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REPORT

ON THE

GEOLOGY OF MARTHA'S VINEYARD.

BY

NATHANIEL S. SHALER.

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The Geological Strata.

The strata composing the earth's crust is divided by most geologists into two great classes: 1. Those generally attributed to the agency of water. 2. To the action of fire; which may be subdivided as follows: (*a*) Aqueous formations, stratified, rarely crystalline (sedimentary or fossiliferous rocks; metamorphic or unfossiliferous). (*b*) Igneous formations, unstratified, crystalline (volcanic, as basalt; platonic, as granite).

The geological record is classified into five main divisions or periods: 1. The Archæan, lifeless and dawn of life. 2. The Palæozoic (ancient life). 3. The Mesozoic (middle life). 4. The Cenozoic (recent life). 5. Quaternary, the age in which man's first appearance is indicated.

PERIODS.		Eras.		Series.	Subdivisions.	
	Age of Primeval Man.	Quaternary or Post Tertiary.		3. Recent. 2. Champlain. 1. Glacial.	Pleistocene.	
Cenozoic Period.	Age of Mammals.	Tertiary Era.		4. Pliocene.	English Crag.	
				3. Miocene.	Upper Molasse.	
				2. Oligocene.	Rupelian and Tongrian of Belgium.	
				1. Eocene.		
Mesozoic Period.	Age of Reptiles.	Cretaceous Era.		4. Laramie.	Upper Chalk.	
				3. Colorado.	Lower Chalk. Chalk Marl.	
				2. Dakota.	Gault.	
				1. Lower.	Neocomian. Lower Greensand.	
		Jura-Trias.	Jurassic	3. Purbeck.	Wealden. Purbeck, Portland, Kimmeridge.	
				2. Oölite.	Oxford Oölites. Lower or Bath Oölite.	
				1. Lias.	1. Lower Lias. 2. Marlstone. 3. Upper Lias.	
			7. Triassic.	4. Rhætic.	Kössen beds, Dachstein beds; Alpine Trias, in part.	
				3. Upper.	Keuper.	
				2. Middle.	Muschelkalk Bunter-Sandstein.	
				1. Lower.		
Palæozoic Period.	Age of Coal Plants.	Carboniferous Era.		3. Permian.	2. Magnesian Limestone. 1. Lower Red Sandstone, or Rothliegendes.	
				2. Carboniferous.	3. Upper Coal-Measures. 2. Lower Coal-Measures. 1. Millstone Grit.	
				1. Subcarboniferous.	Lower Carboniferous. Mountain Limestone.	
	Age of Fishes.	Devonian Era.		5. Catskill and Chemung.	Catskill Red Sandstone. Chemung.	Old Red Sandstone.
				4. Portage.	Portage. Genesee Slate.	
				3. Hamilton.	Hamilton beds. Marcellus Shale.	
				2. Coniferous.	Upper Helderberg, Schoharie, Grit.	
				1. Oriskany.	Oriskany Sandstone.	
	Age of Invertebrates.	Upper Silurian.		3. Lower Helderberg.	Lower Helderberg.	
				2. Onondaga.	Onondaga Salt Group. Salina beds. Water Lime.	
				1. Niagara.	3. Niagara Group. Wenlock Group. 2. Clinton Group. 1. Medina Sandstone.	Upper Llandovery.
		Lower Silurian.		3. Trenton.	3. Hudson River beds. Cincinnati Group. Lower Llandovery. 2. Utica Shales. 1. Trenton Limestone. Caradoc and Bala Limestone. Black River Limestone.	
				2. Chazy.	Chazy Limestone.	
				1 Calciferous.	Calciferous Sandrock. Magnesian stone.	
		Cambrian.			Lower, Middle and Upper Cambrian.	
Archæan Period				Eozoic (dawn of life). Azoic (lifeless).	1. Laurentian. Huronian.	

REPORT ON THE GEOLOGY OF MARTHA'S VINEYARD.

By Nathaniel S. Shaler.

INTRODUCTION.

The following report on the geology of Martha's Vineyard is one of three separate studies which I have devoted to the interesting field of southeastern Massachusetts; the second, that on Nantucket, it is hoped may be soon issued; and the third, on Cape Cod and the Elizabeth Islands, is now in preparation. The special aim of these reports is to furnish a basis for the geological history of this part of the shore line of North America.

As the larger part of this district shows only deposits of the glacial age, the material of these inquiries principally concerns the work of the ice sheet of that epoch. On Martha's Vineyard, however, there are, as is well known, considerable deposits of the Tertiary age, which are the northernmost deposits of that geological horizon on the eastern coast of the United States. As will be seen in the following pages, these Tertiary beds of the Martha's Vineyard series present certain important peculiarities from which we shall be able to make many inferences as to the physical conditions in this district during that time. The literature concerning the geology of Martha's Vineyard is limited.[1] The poverty of the literature is the more remarkable when we reflect that Gay Head presents by far the most striking geological features on our eastern shore.

---

[1] Incidental references to the geological structure of this district are numerous. The following are some of the more important papers concerning the geology of Martha's Vineyard: A letter concerning Gay Head, Rev. Sam. West, Mem. Am. Acad., vol. 2, 1793; Description of Gay Head, Dr. William Baylie, ibid.; Observations on the geology of the United States, explanatory of a geological map, William McClure, Trans. Am. Phil. Soc., vol. 6, 1809; Notices of the geology of Martha's Vineyard and the Elizabeth Islands, Rev. Ed. Hitchcock, Am. Jour. Sci., vol. 7, 1824; Geological essay on the Tertiary formation in America, John Finch, ibid.; Review of "Outlines of the geology of England and Wales, with an introductory compendium of the general principles of that science," Rev. W. D. Conybeare and William Phillips, ibid.; Report on the geology of Massachusetts, Ed. Hitchcock, ibid., vol. 22, 1832; Review of Chas. Lyell's On the Tertiary Strata on the Island of Martha's Vineyard, of Massachusetts, ibid., vol. 46, 1844; Address delivered at the meeting of the Association of American Geologists and Naturalists held in Washington, Henry D. Rogers, ibid., vol. 47, 1844; On the physical geology of the United States east of the Rocky Mountains, and some causes affecting the sedimentary formations of the earth, W. W. Mather, ibid., vol. 49, 1845; On the fossil crab of Gay Head, Dr. Wm. Stimpson, Boston Jour. Nat. Hist., vol. 7, 1863.

The party-colored Tertiary sands exposed in the section near Gay Head light-house make this part of the shore extremely conspicuous. These beds contain a greater variety of fossils than can be obtained in any other part of the coast region of New England.

As will be seen in the subsequent pages which treat of the economic resources of the Gay Head series, this rock yields some clays and sands useful in the arts. Certain of the beds may also prove valuable for fertilizing materials, while the lignite deposits which abound in this section may possibly have a certain value as sources whence iron pyrites may be obtained. The considerable economic possibilities afforded by this series of beds, together with the purely scientific interest which attaches to them, are sufficient warrant for the extended consideration which they have here received.

It will be observed that this report contains no discussion of the fossils found in the Tertiary deposits of Martha's Vineyard. A chapter on this subject was prepared, but it became evident to me that it would be necessary to procure by systematic excavations far more material than is now accessible before the work could be suitably done. I hope to undertake this task in a separate memoir.

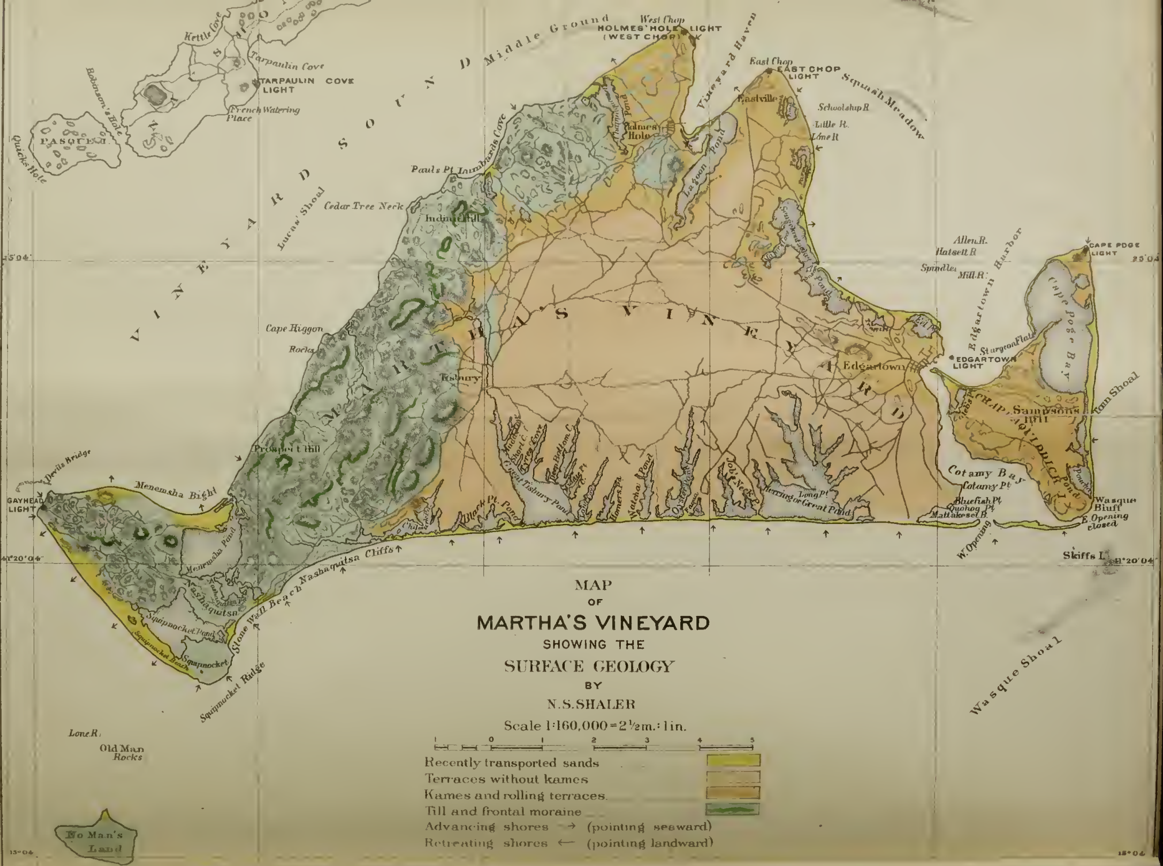
Note

GENERAL GEOLOGICAL RELATIONS OF THIS AREA.

The island of Martha's Vineyard, as will be seen from the inspection of any good map, is a part of an extensive fringe of low land, mainly composed of glacial drift, which extends from New York City to Cape Cod. These beds are represented beneath the surface of the sea by the great fringe of sandy reefs known as Nantucket Shoals and by the extensive submerged deposits of apparently similar nature which exist in the shoal water to the north of Cape Cod known as George's Shoal, Cultivator Shoal, etc.

The part of this belt of glacial deposits which is above water is composed of an outer series of drift ridges which form Long Island, the island of Martha's Vineyard, Nantucket, and a number of lesser islands, and a similar inner ridge evident in Cape Cod, the Elizabeth Islands, and several smaller islands. It is possible that this inner line of drift deposits is continued westward in the northern half of Long Island, which may thus combine the two drift belts in one mass.

The eastern portion of this double coast fringe is separated from the western portion by a considerable gap, i. e., that which divides Martha's Vineyard from Block Island and Long Island. The cause of this break is not perfectly clear, but it is probably due, not to any failure of the glacial deposits to be formed in this space or in any considerable degree to their erosion, but rather, it is likely, to the fact that the floor on which they rest was originally lower in this part of the coast than elsewhere. This is indicated by the circum-



MAP
OF
MARTHA'S VINEYARD
SHOWING THE
SURFACE GEOLOGY
BY
N.S.SHALER

Scale 1:160,000 = 2½m.: 1in.

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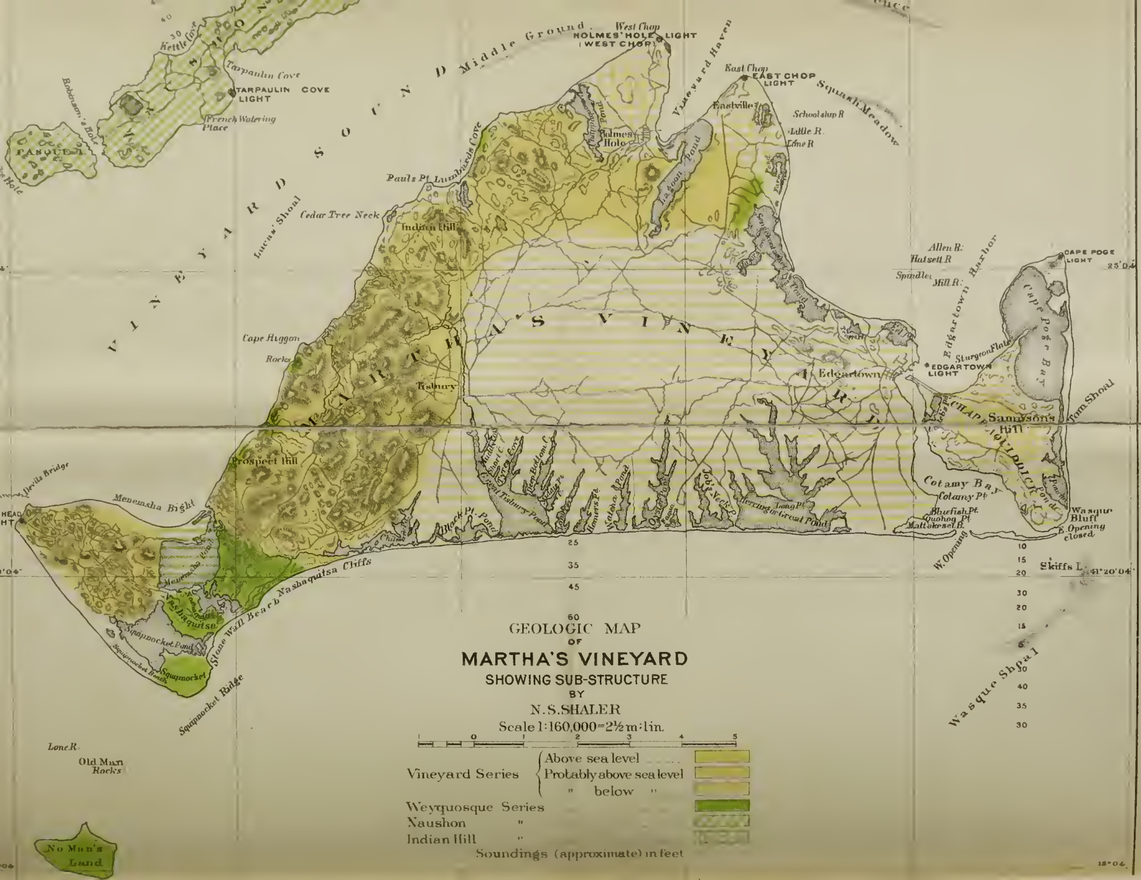


GEOLOGIC MAP
OF
MARTHA'S VINEYARD
SHOWING SUB-STRUCTURE
BY
N. S. SHALER
Scale 1:160,000=2½ m:1in.

stance that from the western end of Martha's Vineyard there is a shoal that extends to Block Island and thence to Long Island. This shoal seems to be a continuation under water of the glacial mass to which Long Island and Martha's Vineyard belong.

On the east, Martha's Vineyard is divided from Muskeget Island, which is essentially a part of Nantucket, by a shallow strait known as Muskeget channel. This channel, though about seven miles wide, is not over fifty feet deep at any point and does not average half that depth. These two islands may therefore be regarded as essentially one mass of land.

The general form of the island of Martha's Vineyard is triangular, with the apex of the triangle turned to the north. The island has a length of about twenty miles and a width on a north and south line of about nine and a half miles. The base of this triangle, i. e., the southern shore of the island, is a nearly straight east and west line from its easternmost point to near its western extremity; at that point it is somewhat abruptly deflected to the south. This deflection, as we shall hereafter see, is due to the geological structure of this extremity of the island. On the eastern end there is a peculiar tangle of sand beaches wrapped round the island of Chappaquiddick, which is barely separated from Martha's Vineyard by an impermanent, narrow, and shoal channel. This channel has been closed during a large part of the present century; it is at present open, as is indicated on the map.

The northern shore of the island is much more irregular than the southern. At the eastern end of the island, Cape Poge, with the very extensive barrier of sand beaches which are attached to it, forms a great salient, within which lies Edgartown harbor. On this northeastern face of the island lies also the extensive inlet known as Sengekontacket Pond. This pond was originally a broad bay which has been barred from the sea by a wall beach of sand. At the very apex of the northern shore is a deep re-entrant

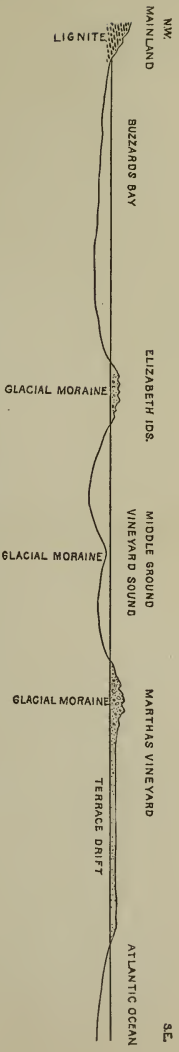


FIG. 55. Diagrammatic section from mainland to Atlantic Ocean, from northwest to southeast.

known as Holmes's Hole or Vineyard Haven, which is prolonged to the southward by a narrow, fjord-like inlet known as Lagoon Pond. These two areas of water form an indentation extending about three and a half miles in a north and south direction. At the western extremity of the island there is another extensive bay which resembles the indentation of Edgartown harbor and is known as Menemsha Bight. Besides these bays, there are two large ponds on the north shore, Chappaquonsett, or Tashmu, and Menemsha, which were originally arms of the sea, but have recently been barred from the open water by walled beaches.

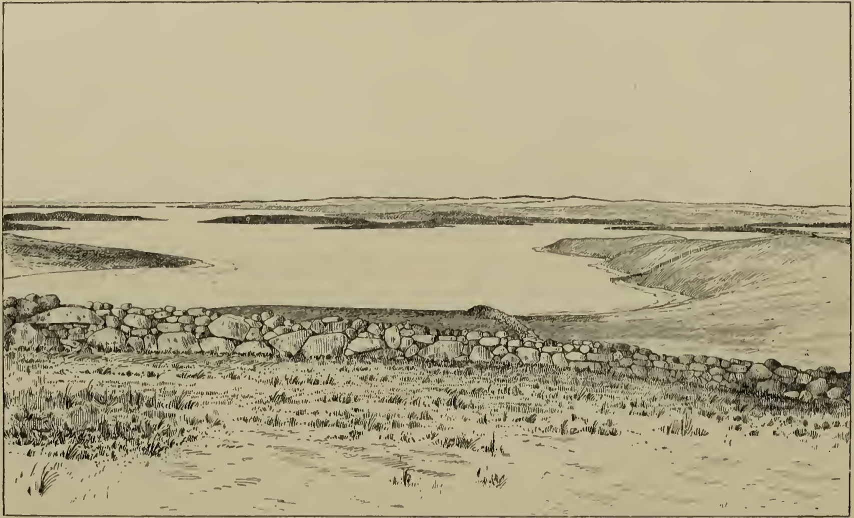
Although the periphery of the island is simple, this simplicity is in good part due to the action of the sea, which by a system of barriers has masked the irregularities of the shore line. This uniforming action of the sea is most conspicuous on the southern face of the island, where the shore is exposed to the assaults of the ocean waves; on the northern shore, which faces Vineyard Sound, this effect of the waves is of course much less pronounced.

SURFACE CONTOUR OF MARTHA'S VINEYARD.

The surface contour of this island is closely connected with its geological structure; it will therefore be well to describe it before entering on its geological history. The surface of Martha's Vineyard is distinctly divided into three parts. On the north side, extending from the western horn of Vineyard Haven to Gay Head, there is a belt of hills composed of sand and gravel interspersed with many large bowlders. This belt of hilly land is on the average about a mile and a half wide. Its ridges have a height of about fifty feet on the eastern extremity of the belt and of about three hundred feet at Prospect Hill, near the western half of the line.

South of this hilly belt, on the eastern half of the island, the surface passes rather suddenly into a plain, which occupies nearly the whole of the area south and east of a line drawn from the village of Vineyard Haven to Chilmark Pond. This plain is at the altitude of about fifty feet above the sea, at least on its northern edge, where it comes in contact with the bowldery hills before mentioned, but it slopes gradually to the south, until, at the southern shore of the island, it rises only about ten feet above the sea level.

West of this plain region we have in West Tisbury, Chilmark, and Gay Head a district where the general surface is much higher than in the other parts of the island, it having an average height of about one hundred and fifty feet above the sea. This district is hilly, but the hills are mainly composed of drift materials, while the deeper part of the mass on which the hills rest is of Tertiary age. Generally the surface of the Tertiary deposits rises to about one hundred feet above the sea.



NASHAQUITSHA AND MENEMSHA PONDS, MARTHA'S VINEYARD, LOOKING NORTH, SHOWING MORAINES CROSSING WATER.

The difference between these three districts is marked not only in their larger features, but in the details of their surfaces as well. The belt of detrital elevations has the usual aspect belonging to deposits of this nature in southeastern New England. They consist of a confused assemblage of hills composed in the main of more or less irregularly stratified sands and gravels mingled with bowlders that are often extremely numerous and of large size. At first sight there appears to be no distinct order of arrangement in these drift hills, but on closer study we see that there is a certain order of distribution in the eminences, their alignment being parallel to the direction of the belt which they occupy. In Pl. XIX these parallel ridges of drift are shown, though in an imperfect manner, forming projections from the shores.

The plain country to the southward is on the whole remarkably level, but on closely examining the surface we find that it is intersected by broad, shallow, and slightly defined channels, which at present are not occupied by streams. These channels widen and deepen southwardly and terminate in the numerous ponds or lagoons which exist on the southern border of the island. These ponds are separated from the sea by the continuous barrier beach which extends from Cape Poge, along the eastern and southern shores of the island, to Nashaquitsa Cliffs, near Gay Head.

The surface of the bed rocks west of Tisbury Brook is to a great extent hidden by the glacial deposits; it is, however, clear that the foundations on which these drift heaps lie is molded into broad elevations, which have a fairly defined north and south axis. On Gay Head one of the troughs between these elevations is so low that the waters of the sea almost cross the island. In this trough lie the basins of Squipnocket, Menemsha, and some lesser contiguous ponds. On the surface of this district the drift materials are accumulated in a very irregular way. Here we find the glacial deposits in such a position that we may see them from top to bottom. This is the most southerly point on the New England shore where it is possible to trace the contact of the drift deposits with the underlying rock. It therefore merits a careful study.

It is worth while to note that on the plain district of the island there is nothing which deserves the name of a brook and on the gravel hills east of this Tertiary district there is not a single stream that is large or constant enough to have received a name. The western part of the island has a number of large and constantly flowing streams, two of which afford good mill power. This difference is clearly due to the presence in the Chilmark district of impervious layers of clay belonging to the Tertiary deposits, which arrest the downward movement of the rainwater and compel it to find its way to the surface before it attains the level of the sea. On the sandy southeastern part of the island the rainwater sinks at once into the ground and enters the ocean in the form of a broad, subterranean sheet which creeps through the interstices of the sand and escapes unnoticed between high and low tide.

The general character of the eastern surface of Martha's Vineyard is essentially like that of the greater part of Cape Cod and almost exactly the same as that of Nantucket, which island, as before remarked, is a part of the same drift deposits. The only important difference to be observed is in the direction of the ridges of drift hills which occupy the northern face of both islands. On Martha's Vineyard these ridges extend in a northeast and southwest direction (or, more accurately, from N. 55° E. to S. 55° W.), a course essentially parallel to the similar ridge which forms the Elizabeth Islands and a considerable part of Cape Cod. On Nantucket, however, the morainal ridges extend in an east and west direction, the difference in azimuth being about 40°. The meaning of this difference will be considered in the report on the island of Nantucket.

The aspect of the two islands differs greatly on account of the peculiarity of the vegetation. Nantucket is essentially treeless, while the greater part of Martha's Vineyard is forest-clad. This difference is probably owing to the greater exposure to the sea winds suffered by Nantucket, which is due to its smaller size and greater distance from the shore. In part the deforested condition of Nantucket may be attributable to the fact that for nearly two centuries its fields were used as open sheep pastures and the young trees were constantly browsed down by the flocks. Martha's Vineyard, on the contrary, has held its woods; only a small strip on the southern shore shows any tendency to become sterilized in respect to forest growth by the action of the sea winds. On the sand plains the woods are of stunted oaks and other dwarf varieties of trees, but the growth is vigorous enough to give a wooded aspect to the surface and thereby to distinguish it in a very marked way from the neighboring and otherwise similar island of Nantucket.

For further considerations on this subject the reader is referred to a forthcoming report on Nantucket.

GLACIAL DEPOSITS OF MARTHA'S VINEYARD.

We have already noted the fact that there is a considerable diversity in the drift materials of this island. The careful examination of the structure of the island shows that there are upon it the following groups of glacial deposits:

1. Ordinary ground moraines or till, such as is left by the melting of a glacial sheet. note
2. Frontal moraine deposits, formed where the materials have been pushed before the glacier. note
3. Kame deposits, where the materials have been brought to their

note position by the action of violent currents of water operating near the ice front of the glacier.

note 4. Terrace deposits, formed by tidal action or by the action of the waves at some distance from the ice front.

It may be noted here that there are no lenticular hills or drumlins on the island and that the group of Indian ridges, or long, wall-like varieties of the kames, is represented by a single deposit of that nature.

We will now consider each of these groups in the order in which they are named:

ORDINARY GROUND MORAINES.

(1) Ordinary moraines and frontal moraine deposits are seen only on that part of the island where they rest upon Tertiary clays which rise much above the sea-level. In the greater part of this district the till is found as a thin sheet in no way differing from the deposits of a similar kind exhibited on the surface of the mainland to the northward. Its average thickness does not probably exceed ten feet, but it is so irregular in this regard that it is not easy to assign it an average depth; considerable portions of the surface are almost bare of it, having only two or three feet of pebbles mingled with the clay derived from the subjacent Tertiary beds. Probably as much as one-tenth of the surface of this district is to this degree wanting in the covering of till. The maps given in this report (Pls. XX and XXI), together with Fig. 56, will give an approximate idea of its distribution.

In its composition the till of the Gay Head and Chilmark districts is much more clayey than that on the mainland. This may readily be explained by the fact that it is in good part derived from the Tertiary beds which it overlies.

This sheet-like till often passes gradually, or at least without distinct demarkation, into steep-sided ridges and hillocks of a somewhat similar nature which are irregularly scattered over the surface of this Tertiary district (Pl. XXII). These drift elevations are generally till-like in their nature, but the materials have evidently been shoved before the glacier and so have the form of frontal moraines. They exhibit obscure traces of stratification; therefore, presumably, they must have been affected by the movements of water. We can most readily account for all their peculiarities of structure by the supposition that they were formed on the sea floor at the front of the glacier during its

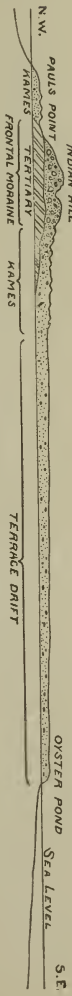


Fig. 56. Diagrammatic section from Paul's Point to Oyster Pond.

period of retreat and shoved forward during the slight and temporary readvances which accompanied that retreat.

A remarkable fact regarding the glacial accumulations which lie on the Tertiary beds is that a good deal less than one-half of their mass was derived from these Tertiary clays and sands. The larger part is from the granitic rocks of the mainland. From an a priori point of view it would seem as if these relatively soft beds should have worn away very rapidly beneath the moving ice, but apparently they have worn but little. In the region of the Narragansett coal-fields, for instance, about Taunton, Mass., in any place which we may choose for examination, more than half the waste composing the till is from points within two miles of the place of deposition. But in these Chilmark deposits, especially along the southern part of that field, we are often able to prove that the till is mainly composed of débris derived from rocks which certainly do not occur within four miles to the north and which were probably not touched by the glacier for more than twice that distance. The failure of the glacial sheet to erode these soft Tertiary beds is probably due in part to the fact that they have no joint planes and also in part to the embedding of the granitic bowlders in the tough clay. In this position the bowlders would in a measure protect the clay from the erosion as by a pavement. Some evidence of this action, it seems to me, may be seen in the section at Gay Head.

The small amount of this erosion is very well shown in the sections at the west end of the island, where the drift is seen in contact with the subjacent Tertiary beds along the marine escarpment for a length of over one-half a mile. It is evident from the small proportion of Tertiary waste in this drift, which does not exceed 10 per cent. of the mass, that the ice took less from these clays than it did from the syenite of the mainland. It is possible that this diminution of the erosion may be due in part to the diminished thickness of the ice near its border. Too much, however, must not be attributed to this cause. The vast amount of coarse débris which was shoved to this point indicates a power of erosion which, though perhaps less than on the mainland, must still have been very considerable.

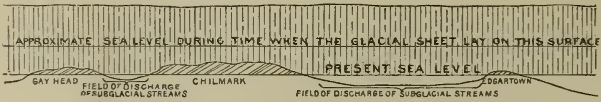
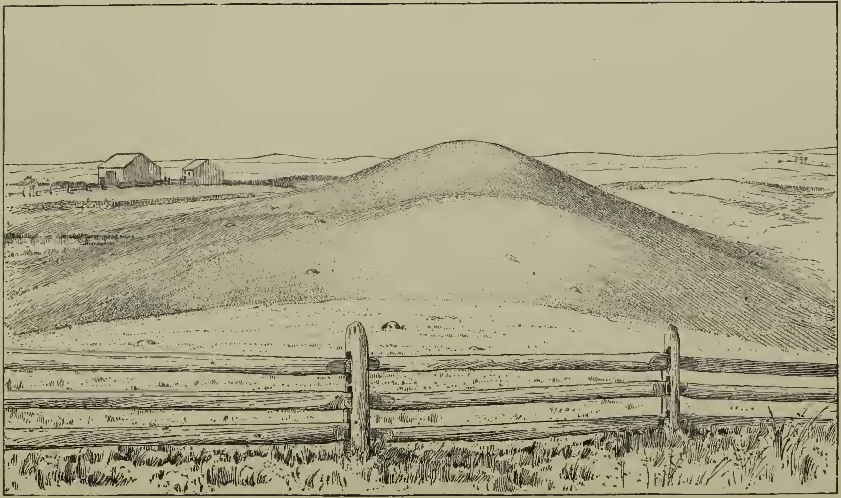

APPROXIMATE SEA LEVEL DURING TIME WHEN THE GLACIAL SHEET LAY ON THIS SURFACE
PRESENT SEA LEVEL
GAY HEAD
FIELD OF DISCHARGE OF SUBGLACIAL STREAMS
CHILMARK
EDGARTOWN
FIELD OF DISCHARGE OF SUBGLACIAL STREAMS

Fig. 57. Diagrammatic section showing theory of position of subglacial streams.

A peculiarity of the drift deposits which lie on the elevated surface of the Tertiary beds is the small amount of ordinary kame drift which exists there. Enough of this kame drift exists to show that the surface was subjected in a slight degree to the forces which dis-



SHARP CONE ON FRONTAL MORAINE, SOUTH SIDE OF GAY HEAD PROVINCE.

posed glacial débris in that form. It seems likely, however, that the elevation of this Tertiary plateau caused the subglacial streams which formed these kames to be diverted to the lower ground on the east and west, so that they existed slightly if at all in the western part of the island (Fig. 57).

FRONTAL MORAINE DRIFT.

(2) We turn now to the frontal and till-like drift which exists in the northern part of the island between Menemsha Pond and Chappaquonsett or Tashmu Pond. The greater part of this section evidently lies on top of the Tertiary beds; only that part which lies west of Indian Hill is unsupported by this pedestal. Even the portion of this line of drift hills which lies west of Indian Hill probably rests on a basement of Tertiary beds, though the surface of that formation is so far hidden that its position cannot well be determined.

This northern moraine drift is essentially like that which is scattered over the northern part of Chilmark and the central part of Gay Head. We may indeed regard it as only a more concentrated form of the same class of drift, and consider it as extending from the seashore about midway between Gay Head light-house and Squipnocket beach northeastwardly to Tashmu Pond, with a considerable interruption at the valley of Menemsha and Squipnocket Ponds.

The essential peculiarities of this district are that in it the distinct sheet till disappears in the crowded hills and that the proportion of stratified or kame-like drift greatly increases. The admixture of clay in the unstratified drift is greatly diminished. From Prospect Hill, which rises to a height of about three hundred feet above the sea, northeastward to Indian Hill this frontal moraine is singularly massive. The general character of the deposit is essentially like that of similar moraines found elsewhere in southern New England. There is a gentle decline in the height of these ridges from Prospect Hill northeastward to Tashmu Pond. East of Tashmu Pond the hills rapidly decline in height and become more kame-like in character, until at Vineyard Haven they are on the whole unlike frontal moraines. This eastward decline in the height of the frontal moraine is probably due to the fact that the surface of the Tertiary beds on which they rest declines in the same direction.

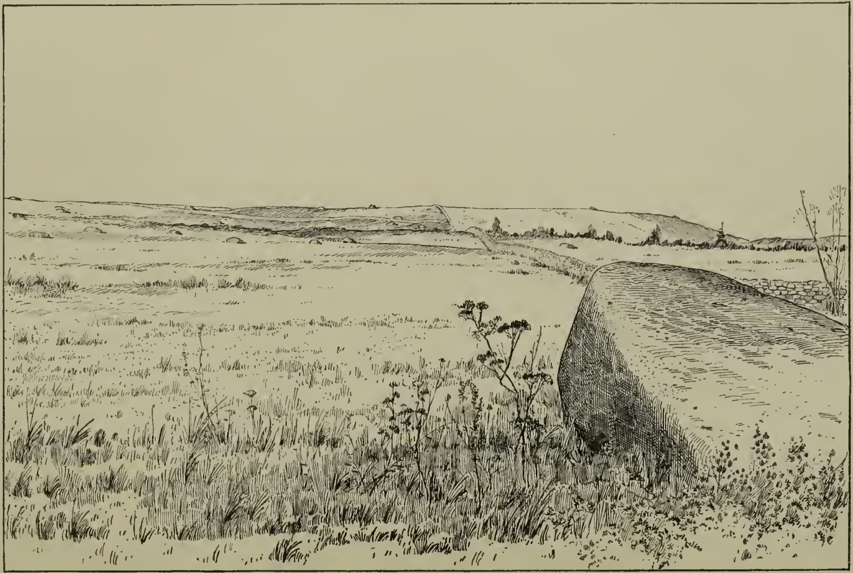
The evidence which serves to establish the hypothesis that these deposits are frontal moraines pushed forward by an ice sheet is as follows: First, the ridges are steep on the iceward and seaward faces; secondly, there is a distinct alignment in these numerous detached ridges; thirdly, this alignment is at right angles to the course of the glacial stream; fourthly, these ridges are in great part composed of large blocks of syenite and other rocks derived from the mainland, which could only have been brought to their present position on the top of the Tertiary beds by the shoving action of an ice sheet. These evidences are sufficient to establish the conclusion that the accumulation of drift on the northwestern face of the island marks the place occupied by the ice front for a considerable period.

The evidence derived from the large fragments of crystalline rocks which make up more than half the mass of many of these ridges would of itself be sufficient to prove that at one time the ice front lay against these hills. In the central part of this northern belt, where the covering of sands deposited from water is somewhat less thick than elsewhere, the massive blocks of syenite are so numerous that on the steeper parts of the hills the bare masses of angular fragments remind the observer of ruined Cyclopean masonry. Over scores of acres in the central portion of this district the large fragments are so thickly packed together that there is hardly any place for soil (Pls. XXIII, XXIV).

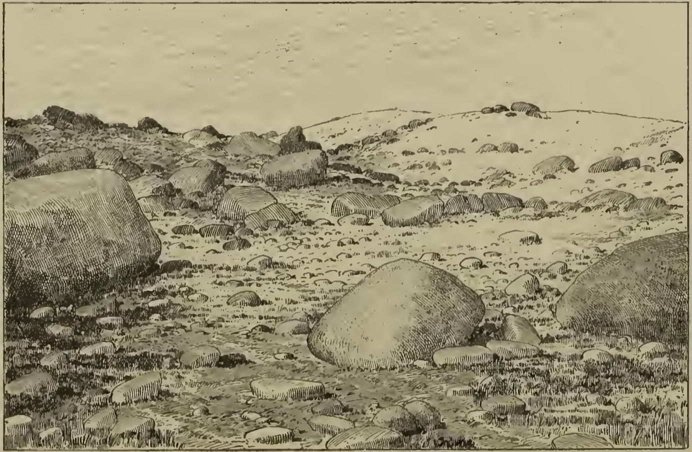
The total amount of detrital material in this belt of moraines between Gay Head and Tashmu Pond is greater than in any other deposit of this nature known to me in New England. On an area about ten miles in length and about one and one-half miles in width the drift cannot be on the average less than one hundred and fifty feet thick. This sheet is therefore equal to a mass of about one-half a cubic mile or about as much material as is contained in the mass of Monadnock Mountain.

As the total mineral matter discharged by the Mississippi River in one year, that in perfect solution as well as that which is in the shape of sand and mud, amounts to only about one-fiftieth of a cubic mile, it follows that this accumulation of drift in the northern part of Martha's Vineyard represents more than the total waste of the Mississippi Valley during a period of twenty-five years. But the field from which this glacial waste of the Vineyard was derived cannot be estimated as having an area of more than one thousand square miles; none of the large blocks is from a point more than fifty miles away, and, while it is probable that some of the small fragments may have been brought from a much greater distance, we may be sure that their mass is much more than counterbalanced by the fine sediments which have been washed away from this morainal belt.

It is a fair inference, from all that we know of glacial carriage, that by far the greater part of the glacially conveyed materials are ground up before they travel any great distance from the point where they were detached from their bed. It is furthermore clear from an examination of any glaciated surface that the greater part of the waste goes away in the form of fine mud; if it were otherwise we should not have all the glaciated hard rock surfaces in the striated or polished shape in which they occur. It therefore seems to me an excessive estimate to say that this mass represents the erosion of a strip ten miles wide, extending one hundred miles to the northward in the direction from which the ice came, during the period while the



FRONTAL MORAINE AT INDIAN HILL, LOOKING NORTHWEST.



SURFACE ON SOUTH SLOPE OF FRONTAL MORAINE, CHILMARK.

ice front lay at this point; yet, by making this assumption we may secure a valuable basis on which to institute some comparisons of the erosive work done by rivers and glaciers.

To those who have studied the rate of erosion in glaciated districts it will be evident that the detrital matter accumulated immediately in front of the glacier can be but a small part of the material transported by the ice. The material removed from the rocks in a finely divided form, as clay or sand, greatly exceeds that which is removed as pebbles or bowlders. It seems pretty certain that the greater part of this fine detritus does not find a lodgment in the frontal moraine, but is carried out to sea. Proof that this is the case will be afforded by a study of the terrace deposits which lie to the southward of the frontal moraine of Martha's Vineyard.

On the supposition that the erosion rate of the ice was the same as that of the Mississippi River, that the area of the erosion was 1,000 miles, and that the whole of the eroded material remains in this frontal moraine, it would appear that the ice front remained at this position for from twelve thousand to twenty-four thousand years. If we conclude that the material gathered in this moraine does not represent the total erosion of 1,000 square miles which took place while it was forming, then we must proportionally extend this term of years. It seems likely that we should then allow from fifty thousand to one hundred thousand years for the time occupied in its formation.

It is not at all likely that the ice front retained its position in the line of this deposit for any such period as that named in the least of these estimates; for, although this is one of the greatest of the lines of morainal matter formed on its front, it is in itself but a small portion of the deposits of this nature which lie on the surface of New England. The neighboring moraine of the Elizabeth Islands is larger than that of Martha's Vineyard. On the mainland south of Canada there is certainly twenty times as much moraine material as is contained within the Martha's Vineyard district.

These approximate computations serve to show that the rate of erosion on a surface exposed to a glacial sheet is many times greater than on a sheet exposed to water action. As I expect to make the subject of glacial wearing in New England the matter of a special essay I shall not deal further with it in this connection.

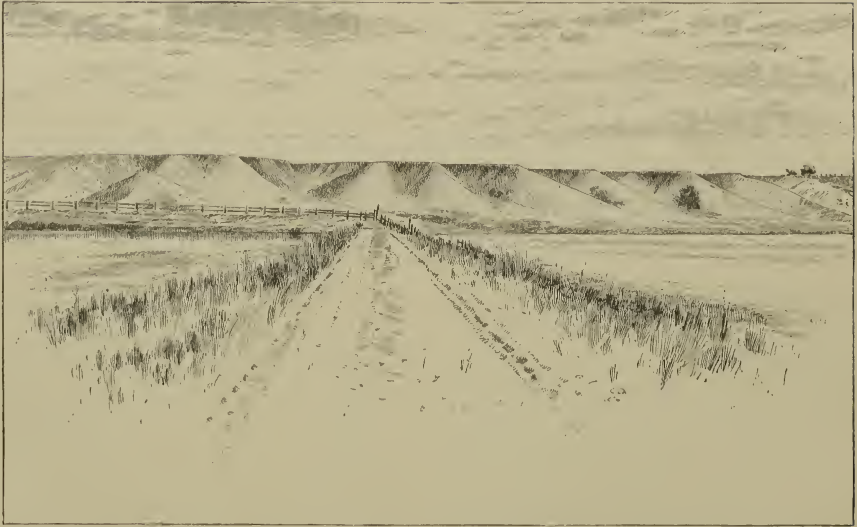
While considering this moraine we may note the fact that it has no distinct extension beyond the limits of the island on which it lies. It is not in any way indicated on the floor of the sea southwest of Gay Head for more than a mile beyond the present line of the cliffs nor on the bottom of the inclosed waters which separate Martha's Vineyard from the mainland. It cannot be doubted that this frontal moraine once extended far beyond its present limits. Any reasonable period of its formation requires us to assume that it at one time formed a part of a fringe which extended from a point where the ice front crossed the sea border a little south of the mouth of the Hudson, along the shore, to the far north. Its complete interruption by the sea at either extremity can best be explained by the hypothesis that this shore has been higher than at present since the close of the glacial period, and that during this period of elevation the seaward extension of the moraines was worn away. This problem is one of particular interest, but too general in its nature and demanding too much consideration to be treated in this report. In another memoir I hope to give it careful attention.

It should be noted that there has been a considerable subsidence of this shore since the completion of the great elevation which took place after the glacial period. The precise amount of this subsidence has not been determined and may be indeterminable. It is also evident that we cannot well account for the presence of the extensive moraines on Nantucket, which were clearly formed when the line of the ice projected far beyond the line of Martha's Vineyard, without supposing that they once existed to the south of the latter island and have been worn away by the action of the sea. A careful inspection of the soundings shows that there is no trace of frontal moraines on the bottom of the sea south of Martha's Vineyard (see Fig. 55).

KAME AND TERRACE DRIFT.

On the southern border of the frontal moraine already described the surface descends first to a series of kame deposits, which in part overlie the southern and lower ridge of the moraine, and then to the wide field of terrace drift, which is better shown on this island than on any other part of New England.

(3) The kames are separated from the frontal moraine by very distinct features due to the circumstances of their formation. They contain only sands and small pebbles which are arranged in distinct, cross-bedded layers, showing that they were formed by the movement of swift currents, which currents were subject to frequent variations in direction and energy. These kames are extremely irregular in their shape; in this particular field they have three types of form, namely: First, those which consist of irregular mounds closely huddled together, which mounds, in some cases, appear to have been subjected to a certain amount of deformation apparently arising from the shoving action of the ice; secondly, we have certain rather continuous ridges which may be principally composed of till or of frontal moraine material coated with kame deposits; thirdly, we have the type, elsewhere commoner than on this island, in which the kames appear as kettle-like depressions on the surface of the drift terraces. These basins often contain smaller irregularities on their floors.



SOUTH END OF LAGOON POND, LOOKING EAST, SHOWING OUTLINE OF KAME AND TERRACE DRIFT.

The distribution of these kame deposits is exceedingly irregular. Where the frontal moraine is high and continuous they are generally wanting. This is the case in the part of the deposit which lies upon the elevated Tertiary beds of Gay Head and Chilmark as well as in that part of Tisbury which lies west of Indian Hill. East of Indian Hill, where the frontal moraine rapidly diminishes in height, the kames are very extensive. They are especially abundant near the southern shore of Chappaquiddick Pond and about the valley occupied by Vineyard Haven and Lagoon Pond. Their abundance in these districts and their rarity in the west part of the island are readily explained provided we accept the theory of their formation which I have elsewhere set forth, which is in effect that they were formed by the irregular, whirling movement of waters that were discharged into the sea from the subglacial streams at a time when the base of the ice drift lay below the level of the ocean[1] (Pl. XXV). The subglacial streams were always strongest in the lowlands. It is doubtful whether they flowed at all on other parts of the surface, as the kames are limited to the valleys of New England.

When the stream was strong it could cut out considerable channels, such as those now occupied by Chappaquiddick Pond and Lagoon Pond, or the channels between the islands of the Elizabeth Islands moraine; but such cutting action would be most common where the drift barriers were least extensive and the least lofty. It seems extremely probable that these channels which crossed the frontal moraine were the paths of streams escaping from beneath the ice. At first sight it may seem unlikely that these streams, when poured into the sea, should be able to scour out channels for a mile or more beyond the ice front, but a similar work is performed where surface rivers enter the sea over the front of an extensive delta, though their currents are probably less rapid than those of the subglacial stream, urged as those streams were to their point of escape by the pressure of the ice as well as by the gravitative force given by their descent from the inland district.

Although the kame deposits are most abundant in the region near the foot of the frontal moraine and in the valleys in which lie Lagoon Pond and Chappaquonsett Pond, there are two other districts on this island in which they are found, though in less abundance and of less characteristic form. One of these is on the western side of Sengekontacket Pond, between Vineyard Haven and Edgartown harbor, another is about Edgartown village, and a third is on the neighboring island of Chappaquiddick. In these outlying fields there is a small though certain admixture of bowlders with the kame material, making it appear as if the ice front of the glacier, during its period of retreat, had remained at these points for a brief period, during which the subglacial stream whirled the sands into the shape of kames.

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[1] On the origin of kames: Proc. Boston Soc. Nat. Hist., vol. 23, pp. 36–44.

As will be seen when we come to consider the shape of the underlying Tertiary deposits, the clays of Tertiary age, after sinking to a considerable depth beneath the level of the sea in the central district of the island, probably rose again to near the level of the tide in the central part of the island of Chappaquiddick as well as in the section adjacent to Lagoon Pond. This would tend to preserve traces of the frontal moraines and the accompanying kames on this part of the island, while these ridges would be effaced in the central part of its area by the deep sheet of stratified drift.

I have been unable to determine whether these last-mentioned kames and moraines were deposited anterior to the time when the principal frontal moraine was formed or at the same time with it. The former supposition requires us to assume that the delicate structure of these outlying kames survived unharmed beneath the sea for a considerable period while the other belts of frontal moraine and kame were forming. This is a somewhat unsatisfactory hypothesis. The other view, namely, that they were formed at the same time with the principal moraine, requires us to suppose that the glacier in this district had a very irregular front, with a deep bay extending up to where is now Vineyard Haven. I am inclined to consider the latter to be the more reasonable of the two suppositions, especially as we should expect a re-entrant angle in the ice front where a large subglacial stream, such as that which passed through the depression of Vineyard Haven, found its way to the sea.

The terrace drift is intimately connected with the kames; they are both composed of stratified sands and gravels, with occasionally large fragments of stone, such as may have been borne out of the glacial front on floating ice. In the kame, beds of gravel are found lying at steep angles, and the direction of the inclination often suddenly changes. In the terrace drift there is an alternation of pebbles and sand, but the changes are much less sudden than in the case of the kames, the beds are more nearly horizontal, and the materials are of finer grain. Moreover, we notice a progressive diminution in the size of the pebbles and sand grains as we proceed southward. On the southern shore, at a distance of three or four miles from the moraine, a small amount of clay appears in the terrace deposits, which accounts for the fact that this portion of the island terrace is more arable than the northern part.

(4) The passage from the form of a kame to that of a terrace is sometimes gradual; again, it is sudden; but, when we proceed far enough away from the kame belt to attain the nearly flat surface of the terrace, it maintains that character southward to the sea. In the distinctly terraced district the surface of the ground is cast in gentle undulations which decline southwardly toward the sea and

also slope eastwardly and westwardly toward the shallow valleys that extend from the base of the kames in a nearly southerly direction to the shore line. These troughs generally terminate in the various ponds or coves which indent the southern shore of the island. In fact, these inlets are formed in the southerly extremity of the depressions where they deepen toward the sea and have been widened by its action. Owing to the fact that the surface of this plain, which occupies the central part of Martha's Vineyard, is covered with a dense growth of scrubby woods, these depressions in good part escape the eye, but if they are closely examined they are seen to have a continuity not indicated on the excellent chart of the Coast Survey, which is the basis of the maps contained in this report. These depressions are best studied on the similar southern plain of Nantucket, where the treeless character of the surface clearly reveals their form. The striking peculiarity of these troughs consists in the fact that though in form much like ordinary stream beds they are not now and never have been the seats of subaërial rivers. Their valleys, often several hundred yards in width, do not present the smooth downward grade so characteristic of ordinary valleys; their floors are generally more irregular than those of any ordinary stream could be. Nor do they have the distinct banks common to all land streams. The only explanation which can be given of these troughs is that they were the channels through which the subglacial streams found their way seaward. It is not necessary to assume that all the streams which formed the several valleys were flowing at the same time; on the contrary, it is most likely that they were excavated in succession by one or two subglacial streams which frequently varied their point of discharge. Observation on existing glaciers shows that such variations would be likely to occur. In fact the difference in the sharpness of outline of the several troughs found on Martha's Vineyard itself suggests the view that they were successively formed. Some of them appear to have been greatly suffused by the mass of sand which has been deposited on them since their formation, while others retain their delicate outlines unimpaired.

There are only two ways in which a long, sloping terrace of sands, declining gently toward the sea, can be produced: one is by the rather rapid rising of the sandy coast from the sea and the other is by the deposition of sands on a sea or lake floor in front of a coast line whence came the sands which form the shelf. In the former case there will certainly remain a number of slight benches marking the successive lines of the coast and there will be no such troughs as those we are now considering. If any such were in existence the first action of the sea would be to erect barriers across them, such as we now find it has formed across the line of every one of these channels where it comes to the shore.

The formation of this inclined plain of sand beneath the level of the sea fully accounts for its general features; for in all respects, except in the presence of the channels before described, it essentially resembles the bottom of the sea as it exists south of this shore. The angle of the slope seaward is the same and, so far as we can judge by the soundings, the character of the materials in the two terraces does not differ in any important respect. The only difference is that on the existing sea floor there appear to be no such channels as we are endeavoring to explain. We are therefore fairly driven to seek the origin of these channels in some forces which were at work during the glacial period, and there are no others which seem available save the subglacial streams, the existence of which is proven to us in many ways.

It has already been observed that these troughs terminate in considerable coves, or fjord-like inlets, which generally debouch into large ponds; for instance, eight of these channels open into Great Tisbury Pond and about as many into Herring Pond, while yet others empty into the smaller ponds of the shore line. Where these channels decline into the coves we find that they have been greatly enlarged and changed in their form by the action of the waves and tides of those water areas; in this way they have been widened and deepened out of all semblance to their original shape. This cutting action of the waves and scouring action of the tides is not shown in these valleys above the present level of the sea, though the steep benches which indicate such work undoubtedly would have remained to this day if they had ever existed.

It is not unlikely that when once instituted by the subglacial stream these valleys would have been somewhat further developed by the to-and-fro movement of the tides along the shore. The outrunning streams from the glacial face would have tended to determine the outflow of the tide into their channels, thus increasing their scouring action.

The question naturally arises, How could the subglacial fresh-water streams have kept their place on the bottom of the salt-water area so as to scour that bottom for some miles from the points where the streams escaped from beneath the ice? To this question we can make the following answer: First, that existing streams along our coast do scour their bottoms and excavate for an equal distance out to sea channels similar to those we are now considering; secondly, that the subglacial stream is always so heavily charged with sediment that it might well be heavier than the water of ordinary rivers. The following table showing the proportion of sediment in some of the subglacial streams of Greenland will make this point clearer:

Solid matter in the glacial streams of Greenland according to Helland

Name of glacier.	Quantity of sediment in cubic meter.
	Grams.
Alangordleck	2,374
Ilartdlek	723
Tuaparsuit	678
Assakak	208
Kangerdlugssuak	278

As the discharge of mud from the great continental glacier of this continent must have been enormous, we may fairly assume that it was equivalent to that of the glacier first named in the above table, or about two thousand grams to the cubic meter. Although the mineral content of ordinary sea water is much greater than this, it is to be remembered that the shore waters near the seat of the discharge of subglacial rivers would probably be much less saline than those which are now found along this part of the Atlantic Coast. In this regard they would resemble the waters near the mouths of our ordinary rivers. It thus appears to be possible that the weight of the subglacial water may have been great enough to enable it to flow upon the bottom for some distance from the glacial sheet. It should also be noted that a stream of water, even if it be lighter than the superincumbent mass, will, if it have a swift movement, force its way along the bottom for some distance before it is displaced by the heavier fluid.

In studying the form of these old channels, especially on Nantucket, where they are best shown, we observe that they gradually widen as they depart from the front of the moraine until at a distance of from three to six miles from their origin they are from five to twenty times as wide as at their source. We also note that the streams which form these channels apparently diminished their energy of movement in proportion to the distance traveled from the glacier. This is shown by the much finer sediment which they laid down in their outer parts. Near their sources they were able to move considerable pebbles, while at their southern extremities they were able to transport fine sand alone.

I desire to say that while these peculiar channels may not in the end appear to be due to the cause above suggested, this cause is the only one out of many considered which appears reconcilable with the facts. They are clearly due to localized streams of some sort which originated at the ice front. They were evidently formed while the surface on which they lie was depressed below the level of the sea, for their troughs do not have the shape of those excavated by subaërial streams.

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[1] Handbuch der Gletscherkunde, by Dr. Albert Heim, Stuttgart, 1885, p. 363.

The depth beneath the sea at which this terrace deposit was built cannot be determined. It seems, however, tolerably clear that all the drift on the island was deposited at some depth below the level of the ocean. The frontal moraine, including the highest of the ridges about Prospect Hill, is composed of materials which would have been much eroded if they had been long exposed to the action of the sea. There is no trace of morainal erosion on their surfaces. It therefore seems necessary to suppose that this shore was depressed considerably more than three hundred feet during the time when these deposits were formed. As this terrace of drift which extends in a gentle decline from the base of the great Vineyard moraine was certainly formed at the same time as the moraine itself, it follows that it was constructed in tolerably deep water.

Besides the before-mentioned deposits of the glacial age there is a series of clays in this district the relations of which are not well determined, but which may have been deposited during the first stages of the glacial period, though they may belong to an age between that of the Vineyard series and the glacial epoch. These clays are particularly well shown in the western part of Chilmark or Weyquosque Cliffs, where they appear commingled with occasional beds of sands and gravels in the manner indicated in the diagram (Fig. 58).

At first I was disposed to regard this Weyquosque series as belonging to the same age as the Vineyard series, but the sections exposed by the storms of the winter of 1885–'86 furnish evidence that they differ entirely in physical characters and that the Weyquosque series appears to overlie unconformably that of the Vineyard.

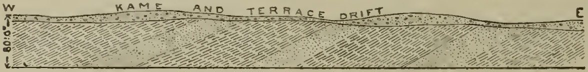

FIG. 58. Diagrammatic section of a part of the Weyquosque series.

As shown in the Weyquosque Cliffs, these beds exhibit many remarkable small contortions and plications which may possibly be due to the sliding of the faces or to the pressure of the advancing glacial sheet; it may be, however, that they are due to the more general conditions of pressure which have flexed the Vineyard series. The great amount of slipping which has occurred on this escarpment makes it extremely difficult to determine any other point save that the general succession is much like that represented in the diagram.

The inclination of these clays, which rises to as much as 15°, is much greater than we should expect to find in a considerable section of such materials. I am therefore inclined to think that they were brought to their present attitude by mountain-building forces, in which case we should have to refer them to the Tertiary series. Unfortunately they seem to be quite wanting in organic remains, so that the positive determination of their age is very difficult.

The emergence of the drift deposits of this district from the sea must have taken place with singular rapidity, for there is no sign of wear on the surface of the moraines or the lower-lying kames such as would inevitably have occurred if their surfaces had been exposed to the action of the waves for any length of time. Nothing save an exceedingly sudden uplift could have secured their escape in the process of elevation; their extremely delicate outlines could not endure the action of the sea for a single month.[1]

It is quite evident that this problem of the sudden elevation of the coast line is one of great consequence to the theory of the general movements of the shore as well as to the history of the glacial period. It merits ample discussion with reference to the whole of the facts which may be gathered on the coast line of New England. These facts will receive attention in a memoir on the recent changes of level of this coast, now in preparation.

In closing this description of these several classes of drift deposits occurring on Martha's Vineyard we may note the fact that there are certain groups of glacial waste which do not appear on this island. Of these the most important are the drumlins or lenticular hills. A careful search of this island has failed to show any forms which could be placed in this class of drift deposits. Several of the hillocks on the elevated Tertiary beds in Chilmark have at first sight a general resemblance to the drumlins of the mainland; but on careful inspection I have been unable to class any of these deposits with that peculiar group of glacially formed hills.

So, too, the group of serpent kames which present a modification of the kame structure, in which the material is more stony, compact, and till-like than the ordinary kames, is scantily represented on Martha's Vineyard.[2] A single rather obscure specimen of this class of morainal deposits is found on the west side of the road from North Tisbury to Cedar Tree Neck, near the Wood school-house.

The reason of the failure of these drumlins to appear on Martha's Vineyard seems to me tolerably clear. The drumlins appear to be masses of till or sometimes, though rarely, of kame or terrace drift which have been formed during a period of glacial retreat and during a subsequent extension of the ice have been eroded by the readvancing glacier in the manner in which any other rock is eroded by glacial

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[1] This feature of the kame and f ontal moraine deposits of New England is also noticed in the report on the island of Nantucket, as well as in the memoir on the origin of kames published in the Proceedings of the Boston Society of Natural History, vol. 23, 1885, pp. 36-44.

[2] In this class of deposits the pebbles are not scratched as they are in the till, the clay element is generally wanting, and the outline of the mass is that of a continuous, rather serpent-like ridge.

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action. They have taken the lenticular form because they are homogeneous in composition, that being the form which a uniform mass of syenite, clay slate, or other rock which presents a uniform resistance to erosion assumes when worn down by a glacier. The conditions which favor the formation of these drumlins were absent from Martha's Vineyard because there was no deep mass of till on its surface to be shaped by the readvancing ice in the latter part of the glacial age.

The serpent-like kames appear to have been formed beneath the glacier near the mouths of the subglacial streams. The only field on Martha's Vineyard on which we can trace the successive retreats of the glacier is on the elevated ground underlaid by the Tertiary beds in the western part of the island, a region in which, as before remarked, there appear to have been no subglacial streams. In the imperfect belt of frontal moraine lying to the east of this Tertiary district the surface is so crowded with the material shoved forward by the ice and with the kame deposits that any serpent kames which may have been formed would have been buried beneath these accumulations. Serpent kames are always among the rarest types of glacial deposits. From their rarity, not more than one or two specimens of this type would be likely, under the most favorable circumstances, to exist on an area like that of Martha's Vineyard.

On the island of Nantucket there are many trustworthy evidences which serve to show that the level of the coast has been somewhat lowered since, at the close of the glacial period, it underwent a swift elevation. On Martha's Vineyard there are no such distinct evidences of recent subsidence, though at Vineyard Haven there are some cases in which dead trees in a marine marsh lie below the level of high tide. On Nantucket the principal evidences are derived from the peat bogs which were originally formed in fresh-water swamps and have recently been depressed below the level of the sea. This difference is probably due to the fact that while on the more eastern island peat bogs are tolerably plenty they are and doubtless always have been less abundant on the island we are now considering. It is not likely that there has been any considerable difference in the amount of subsidence to which these two islands have been subjected.

ORIGIN OF GLACIALLY TRANSPORTED MATERIALS.

The origin of the glacially transported materials found on Martha's Vineyard has been carefully sought for in the hope that it would furnish information as to the direction of the ice movement in this district and perhaps afford some clew as to the deposits which lie buried beneath the drift or under the sea between this island and the mainland.

It is necessary to state at this point that the materials transported by the subglacial streams and accumulated in the kame and terrace deposits were generally transported for a greater distance than the débris which was carried in the body of the ice. A careful inquiry as to the transportation of glacial waste, especially in the valley of the Taunton River, has shown that the average carriage of the till material from its point of origin to the place where it now lies is less than one-fifth the distance to which the kame and terrace material was conveyed. This difference might be attributed to the fact that the kame as well as the terrace drift contains smaller pebbles than are found in the till. In drift of all kinds the size of pebbles diminishes with the distance to which they are carried. Making allowance for this, however, it is still clear that the kame drift of any district has been transported for a much greater distance than the till drift of the same district. This is a result which would have been expected on a priori considerations; the subglacial streams must have moved with much greater speed than the ice beneath which they flowed; they would transport the fragments which they bore along to a greater distance than that to which the ice would convey its waste. Moreover, it is easily seen that the pebbles in these flowing streams would be less exposed to destruction than those contained in the lower part of the ice, which, as is shown by their scratched and faceted surfaces, were in succession held down upon the bed rock and ground away as the ice bore them on.

These considerations will make it necessary to study the materials of kames and till apart from each other. In this work the till and the frontal moraine may be regarded as of one nature.

The pebbles in the kame and stratified drift are so small that it is difficult, if not impossible, to determine their place of origin in the rocks of the mainland with sufficient accuracy. It is, however, evident, from my inspection, that in large measure these materials were derived from points lying beyond a line drawn from Boston to Providence; that is to say, from more than fifty miles to the northwest of Martha's Vineyard. This is shown by the fact that the crystalline rocks represented by the pebbles in this kame and terrace drift are in good part of the classes of rocks which are only known north of that line. The principal part of our attention must be given to the frontal moraine and till represented on this island.

Beginning on the western extremity of the island, we find the bowlders composed in large part of syenitic rock; the larger and more angular blocks are altogether of this material. Many of these erratics are very angular and of considerable size; the largest contain about one hundred cubic feet of rock each. There can be little doubt that these masses are altogether from the syenite[1] which lies along the south shore of the mainland from near Newport to the head of Buzzard's Bay, which probably in large part constitutes the foundation rocks beneath the sea and under the islands which lie to the

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[1] The term syenite as here used designates the familiar combination of quartz, feldspar, and hornblende now known by petrographers as hornblendic granitite.

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north of Martha's Vineyard. The generally angular form of the fragments is good evidence that they have not beencarried from a distance; moreover, the syenite has the porphyritic character peculiar to that rock in this district. Mingled with these are fragments of sandstone, generally not exceeding twenty cubic feet in mass, which are doubtless from the Carboniferous district of the Taunton Valley that lies to the north of the before-mentioned syenite.

The Coal Measures of the Taunton district contain numerous beds of conglomerate representing the millstone grit. These conglomerates are especially well developed in the part of the Narragansett coal-fields which is south of Dighton. They exist on both sides of the Taunton River and extend from Seekonk and Somerset to near Lakeville, Mass. We note the fact that these conglomerate bowlders are relatively abundant on Martha's Vineyard. The black slates and shales, which are much the more abundant materials in the Carboniferous series whence these bowlders were derived, are not represented in the glacial drift of Martha's Vineyard. This shows us how far the transportation of materials by glacial action depends upon the resistance which they offer to the strain incident to this method of carrying. Such wearing out is probably due not only to the friction of pebbles against one another and against the bed rock, but probably also to the shearing movement which pervades every part of the ice. This movement tends to break into bits every fragment which is penetrated by numerous fissure planes, as are these slates and shales of the Coal Measures. It is only the little-jointed rocks which stand this shearing movement. We may remark, in passing, that this shearing movement is proved by the way in which the ice is turned around every prominence, even the slightest, that interferes with its motion.

There are many other rare varieties of rock found in the region near Gay Head, but they are all fairly recognizable as dike or vein stones, such as are known to occur in the before-mentioned Carboniferous rocks or syenites. A few infrequently represented varieties, certainly not forming more than a thousandth part of the whole, are derived from the district northwest of the line of the Boston and Providence Railroad.

One of these rare erratics from beyond the before-mentioned line, as yet represented in my field-notes by a single bowlder, is from the ilmenite, or titaniferous magnetic iron ore, which occurs in a solitary, very circumscribed locality in the town of Cumberland, about four miles east of Woonsocket, R. I. This very remarkable mineral is not known to occur in place in any other locality in this part of New England, and in this locality it is limited to a single hill which has a length of not more than one thousand feet, a width of not more than six hundred feet, and a height of not over sixty feet. The bowlder trail from this hill has been traced to the south from its point of origin to the southern part of Narragansett Bay, where it appears to occupy the whole width of the bay from the eastern shore of Aquidneck Island to the mainland on the western side of that bay. The prolongation of its course would carry the line of this trail much to the west of Martha's Vineyard; but here, as elsewhere along the New England coast, the path of the ice appears to have deflected slightly to the east after it escaped from the land. This deviation has brought the trail over the southwestern border of Martha's Vineyard. This specimen was found on the south side of the island, one-half mile west of the western end of Squipnocket Pond. The fragment weighed about ten pounds; it was not much rounded; all of it except a small point was buried in the till; the small projecting portion was decidedly decayed; the peculiar feldspar crystals which are dotted through the magnetite were worn into deep pits; the buried portion was undecayed. There can be no doubt that the specimen had been carried by the ice, for it was actually embedded in the drift. It can therefore be assumed that a line from this place to the point whence the fragment came will give us a close approximation to the direction in which the ice moved in its course from what is now Cumberland, R. I., to this part of Martha's Vineyard. The direction thus obtained is northwest to southeast. The special studies made upon this bowlder trail in my forthcoming report entitled "On the glacial trail extending from Iron Hill, Cumberland, R. I.," will show that this is only an approximate determination of the direction in which the ice moved, for the reason that there is a certain fanning out or divergence of the trail as we go southward from its source; i. e., though at its source it is only 600 feet wide, it becomes as much as 30,000 feet wide at a point only 25 miles south of its origin. Still this divergence could not lead us to an error of more than five degrees in our estimation of the direction of the glacial movement. It thus gives us much more definite evidence as to the course of the ice in this part of New England than can be obtained from any other source.

The pebbles on the eastern side of the island are more varied in their mineral constitution, closely resembling those of Nantucket. They are generally of hypogene rocks.

CRETACEOUS ROCKS OF MARTHA'S VINEYARD.

Rocks of Cretaceous age occur under peculiar conditions at two points on this island. In both places the material occurs commingled with the glacial drift, but under conditions which make it certain that the waste is from a position very near the place where it is now found. The most interesting and instructive of these localities is nearly south of Indian Hill, in immediate proximity to the serpent-like moraine before described and a few hundred feet east of a ruined building known as the Wood school house. At this point the sandy till, or frontal moraine, is plentifully commingled with small, angular fragments of a reddish sandstone, which contain six or eight well marked species of Cretaceous mollusca. These fragments, which are so numerous that it would be easy to accumulate many tons in weight of the material, are limited to a superficial area of less than an acre. They constitute nearly the whole of the coarser matter contained in the deposit. Their distribution, their friable nature, and the fact that a very careful though fruitless search has been made in order to discover any extension of the deposit satisfy me that the Cretaceous beds whence these fragments were derived are in place at some little depth beneath the surface, within a few hundred feet of the locality where the Cretaceous waste now lies.

At one other point, namely, on the eastern shore of Lagoon Pond, the drift deposits for a north and south distance of two or three hundred feet contain occasional, though rather rare, fragments of the same or similar Cretaceous beds. At this last-named point the material seems to have been transported for a greater distance than that found near Indian Hill. Nevertheless the angular structure, as well as the frail nature of the waste, makes it clear that the transportation has not been for any considerable distance.

On the island of Chappaquiddick and in the region near Edgartown, occasional fragments of a ferruginous sandstone are found which closely resemble in their general character the materials containing the Cretaceous fossils, but as they afford no organic remains I hesitate to consider them of that age.

In the present imperfect state of our knowledge of these interesting beds we can say but little concerning them. It seems to me, however, tolerably clear that there must be at least two patches of rocks of Cretaceous age on the island of Martha's Vineyard, and that the deposits consist, in part at least, of thin-bedded ferruginous sandstones containing abundant marine fossils. My assistant, Mr. Aug. F. Foerste, has made a detailed search of the whole surface of the island for other deposits of the same nature, with negative results.

TERTIARY ROCKS OF MARTHA'S VINEYARD.

We are now to consider the Tertiary deposits of this island. These deposits, limited in extent and imperfectly exposed as they are, deserve a very careful study. They are the most northern of all the known Tertiary beds on the eastern versant of North America; they thus afford us information concerning a portion of the continent during that time which cannot be had elsewhere.

The Tertiary deposits of Martha's Vineyard are distinctly exposed to view in but a small part of the island. They lie above the level of the sea only in the district west of the meridian drawn through the village of West Tisbury and in a small area near the head of Lagoon Pond. In the greater part of the Chilmark district the surface of these beds lies above the sea level, but along the whole shore line (except near Gay Head and at Chilmark Cliffs, called on the Coast Survey map Nashaquitsa Cliffs) these Tertiary beds sink below the level of the ocean. They are also below that level in the belt of lowlands occupied by Menemsha and Squipnocket Ponds. It is quite possible that these Tertiary deposits rise above the level of the sea at several points on the eastern half of the island, but, if so, they are, except in the southern part of Lagoon Pond, hidden by the thick coating of drift. It is indeed probable that on the island of Chappaquiddick they lie above the level of the sea, as appears from the fact that numerous fragments of the Tertiary waste are contained in the drift at that point. It is also very probable that they lie above the level of the sea in the region about Tashmu Pond.

Having determined that the Tertiary deposits exist at both extremities of Martha's Vineyard, we may fairly assume that they extend between these two points, and indeed that the portion of the beds exposed on this island is only a part of a much more extensive but imperfectly disclosed area. I am inclined to believe that they exist under a greater part of the Elizabeth Islands district and a portion of Cape Cod. There is also evidence, derived from some chance bits of Tertiary rock which have been brought from the sea bottom by the dredge, that deposits of Tertiary age are extensively developed along the Atlantic Coast.

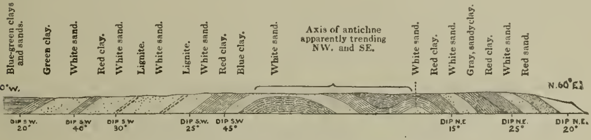


FIG 59. Diagrammatic section of Chilmark series.

The apparent occurrence of Tertiary beds in the submarine area bordering New England makes it important that we should search the shore land of this region for localities, as yet unknown, where these beds are exposed above the level of the sea.

Although there is an area of about thirty square miles of Tertiary beds on Martha's Vineyard, and although these rocks in places rise to the height of 200 feet above the sea level, there are only two points where the beds are shown in clear section or where their presence would be remarked by any one not a geologist. Over the surface of Gay Head and Chilmark the glacial drift, though often very thin, is generally so continuous that the underlying Tertiary deposits are very rarely disclosed. At certain stages of the erosion of the Nashaquitsa Cliffs the beds of Tertiary age are imperfectly disclosed near the base of that section (Fig. 59).

The Tertiary beds of Martha's Vineyard have evidently been somewhat eroded by the glaciers of the last ice period; it is, however, equally evident that they have not been more worn than the hard, crystalline rocks of the mainland. The section at Gay Head shows that the soft Tertiary clays have not rapidly yielded to the rubbing action of the ice, but, as before remarked, they have probably been protected by the adhering glacial waste from such wearing. The amount of the Tertiary waste which is contained in the drift is small, not over one-tenth of the till material in the southern part of the Gay Head section being composed of it, though we are compelled to believe that the ice which deposited this drift had journeyed over the surface of these Tertiary beds for at least a mile, and probably for a much greater distance.

The form of the surface of the Tertiary beds compels me to believe that they retain in good part the shape which they had before the beginning of the last glacial period. If we could remove all the glacial waste from this surface we should find that it had a contour closely resembling that of the chalk downs in southern England. We should see broad, rolling hills sloping gently to infrequent valleys, a topography characteristic of a land surface where the rain, frost, and stream had long and steadily acted upon beds of the uniform nature which characterizes the Vineyard series. I cannot believe that this topography could have been formed by the abrading action of the ice or could have been to any considerable degree affected by such action. If this view be accepted it is clear that this ground was near the southern edge of the ice sheet.

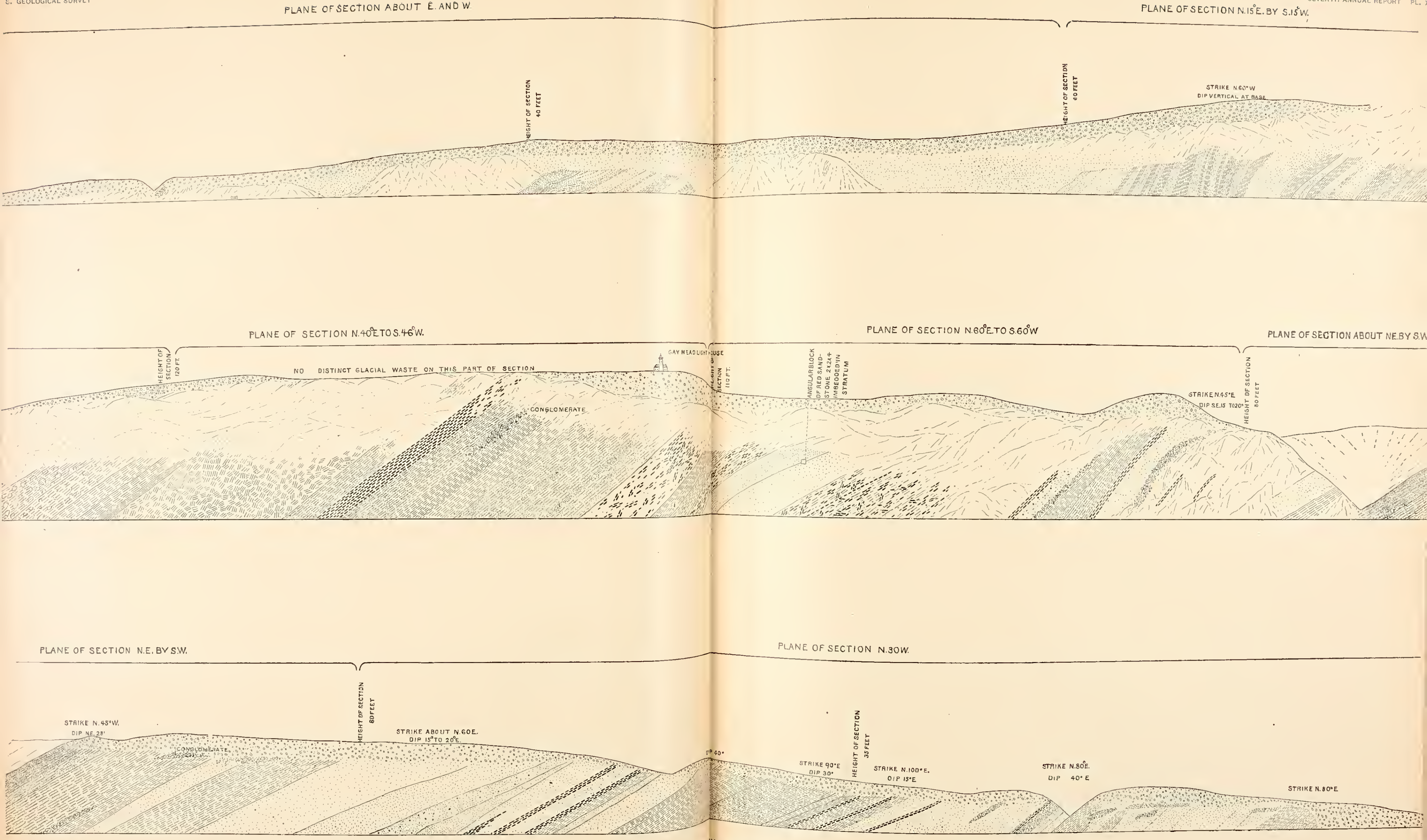
STRATIGRAPHY OF THE VINEYARD SERIES.

We shall begin the study of the stratigraphy of the Tertiary deposits of Martha's Vineyard with the section at Gay Head.

The Gay Head section consists of three divisions: The central part (i. e., that part which faces nearly west) has a length of about thirty-five hundred and an average height above the sea of about eighty feet. At the southern end of this section there is an exposure of about two thousand feet in length, which trends toward the southeast. At the northern end of the principal section there is another short and incomplete section which trends nearly east and west. These three divisions constitute one great and nearly continuous sea cliff having a length of over six thousand feet. The cliffs of this section are from ten to eighty feet in height. Throughout nearly its whole length the escarpment is rapidly wearing away, so that with trifling exceptions it exposes fresh surfaces to view from decade to decade.

The aspect of this section varies much from year to year. The delineation given in the plates represents the results of studies made between 1883 and 1887.

The face of this cliff shows us a great number of thick, steeply inclined beds of sand, clay, and lignitic matter, of extremely vivid and contrasted colors. The colors range from the dazzling white of the


PLANE OF SECTION ABOUT E. AND W.
PLANE OF SECTION N.15°E. BY S.15°W.
HEIGHT OF SECTION 40 FEET
HEIGHT OF SECTION 80 FEET
STRIKE N.60°W
DIP VERTICAL AT BASE
PLANE OF SECTION N.40°E.TO S.46°W.
PLANE OF SECTION N.60°E.TO S.60°W
PLANE OF SECTION ABOUT NE.BY S.W.
HEIGHT OF SECTION 120 FT.
NO DISTINCT GLACIAL WASTE ON THIS PART OF SECTION
GAY HEAD LIGHT HOUSE
HEIGHT OF SECTION 110 FT.
ANGULAR BLOCK OF RED SAND-STONE 2X2X4 IMBEDDED IN STRATUM
CONGLOMERATE
STRIKE N.45°E
DIP S.E.15 TO 20°
HEIGHT OF SECTION 80 FEET
PLANE OF SECTION N.E. BY S.W.
PLANE OF SECTION N.30W.
STRIKE N.45°W.
DIP NE.28°
CONGLOMERATE
HEIGHT OF SECTION 60 FEET
STRIKE ABOUT N.60E.
DIP 15° TO 20°E.
DIP 40°
STRIKE 90°E
DIP 30°
HEIGHT OF SECTION 35 FEET
STRIKE N.100°E.
DIP 15°E
STRIKE N.80E.
DIP 40°E
STRIKE N.80°E.

APPROXIMATE SECTION OF THE BEDS EXPOSED IN THE CLIFFS AT GAY HEAD MARTHA'S VINEYARD.

sandy beds to the nearly pure black of the Carbonaceous layers, with intermediate hues of brown, green, yellow, and red. When the observer has become accustomed to the singular nature of the scene, he perceives that these colors are closely related to the mineral composition of the beds and that the hues are repeated several times in the length of the section (see Pls. XXVI, XXVII, and XXVIII).

The orderly arrangement of the beds in the section is greatly masked by the continued slipping of large wedges of the deposits down the steep incline of the talus. When we apply a correction for this slipping the beds are seen to lie in a tolerably regular order, dipping usually to the northeast, with inclinations varying in general from twenty to sixty degrees of declivity, but rising in one place to ninety degrees. The following distinct varieties are observed in these beds:

First, a whitish sand, which is the most abundant element in the section. This sand is generally composed of coarsely powdered quartz, feldspar, and mica, the last being the least abundant element in the mass; it contains also, though rarely, decayed, hornblendic crystals. Occasionally small masses are found where the quartz, feldspar, and mica are still united, but these bits are always much altered. At certain points in the section the white sand is composed almost entirely of finely divided quartz; in other beds feldspar or mica greatly predominates. The material composing this white sand seems to be essentially a powdered, granitic rock. None of the beds shows any admixture of materials other than those which might have been derived from the destruction of granite.

The next most conspicuous beds are those of red clay. These beds are not so continuous as the preceding; they commonly contain layers of the whitish sand and they always lie in immediate relation to those sands, occurring either immediately above or immediately below them. These reddish clays often contain masses of sandstone, generally of a reddish color and angular form; the largest of these fragments does not exceed ten cubic feet in mass. In their lithological character these fragments have a general resemblance to the red sandstones of the Connecticut Valley, though they are not exactly like any of those deposits which are known to me.

The third group of these deposits comprises the brown and greenish clays and sands which have commonly been termed "greensand." This group of deposits is limited to the northern end of the section and has much less thickness than the red clays or the white sand. They consist, in fact, of a single set of beds, the layers of which are separated from one another by partitions of lighter-colored deposits. This section is much more ferruginous than the preceding. It is also noteworthy from the fact that in certain parts it contains numerous fossils, vertebræ of whales, sharks' teeth, etc., and many nodules of lime phosphate. These nodules have not been recognized in any other part of the Gay Head section.

We have now to notice the most remarkable deposits which occur in this section. These are the lignites, of which there are more than a dozen distinct beds, some of which are divided by narrow partitions of clay and sand, so that the total number of the lignitic layers exceeds thirty. Their thickness varies from forty feet or more down to an inch. Their position and their approximate thickness are indicated in the general section (Pl. XXVI). All these beds are of a dark-brown or black color. The proportion of vegetable matter varies from 15 per cent. to 80 per cent. of the mass, the inorganic matter being in part the ash of the plants, but in larger part clay and sand. In places the mass is composed almost entirely of finely divided woody matter, commingled with stratified clay, in which, here and there, are found fragments of trunks and branches of trees. These fragments appear to have been subjected to much attrition before they were deposited in their beds.

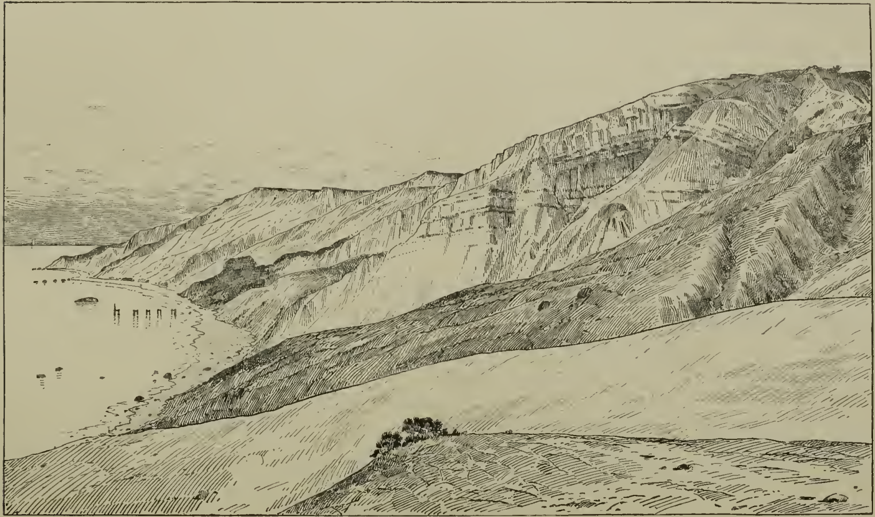
In the greater part of these lignites we find a large amount of iron pyrites in the form of nodules, as well as frequent crystals of selenite. Two or three small fragments of a fossil resin have been found in the uppermost beds of this lignite. This resin is indistinguishable by ordinary tests from amber. Although the lignites are found in every part of the Gay Head section it is only in the upper half of the series that they attain to any considerable thickness. It seems to me pretty certain that these beds are characteristic of the upper portion of the Vineyard series and that when they begin to appear in the section the coarse-pebbly beds as well as the whitish sands begin to disappear.

It will be seen that the history of these lignites, which are distributed throughout the whole of this great section, has a most important bearing on the determination of the origin of the series to which they belong.

Considered in a general way this section may be said to give us a somewhat rhythmical succession of clays and sands alternating with lignite beds which are scattered through the series.

ANALYSES OF DIPS IN VINEYARD SERIES.

The following table gives the dips and strikes of the several beds, beginning at the southern or lowermost part of the section and proceeding northwardly. The numbers in the second column give the distance in yards from the point of beginning; those in the third column, the direction of the section plane or general face of the cliff; the fourth column gives the thickness of the bed, determined as carefully as the slipped condition of the escarpment will admit; the fifth column, the direction of strike; the sixth, the angle and



GAY HEAD CLIFFS, LOOKING SOUTH.

direction of dip. Only a few of the whole number of beds are represented in this list:

Analysis of the dips etc. of the section.

Nature of bed.	Distance.	Face of cliff.	Thickness in feet.	Strike.	Dip.	Remarks.
Conglomerate	60	N. 31° W.	2	N. 45° E.	38° E.	Very local deposit.
Red and yellow sand and clays	180	....do.. ..	40	N. 80° E.	N. 45° E.	
White sand	210	....do	20	....do	N. 40° E.	
Lignite	300	....do	2	....do	N. 30° E.	
Conglomerate	350	....do	3	?	N. 57° E.	
Lignite	380	....do	4	N. 100° E.	40° E.	
Yellow sand etc........	500	....do	30	N. 50° W.	45° E.	
Gray-white sands........	600	N. 27° W.	20	N. 30° W.	15° E.	
White sand...........	650	....do	15	....do	25° E.	
White, sandy clay	750	....do	30	N. 45° W.	28° E.	
White sands, clays, and lignites	900	N. 15° E.	25	N. 45° E.	15° E.	Sudden dislocation of this part.
Whitish sands..........	1,150	....do	20	N. and S.	25° E.	
Ferruginous sands	1,200	N. 10° W.	12	N. 20° W.	20° to 30° E.	
Lignites	1,400	....do	20	....do	40° E.	
"Greensand"	1,700	....do	50	N. 45° E.	50° to 90° E.	The strike is local.

It is evident that the prevailing dip of these deposits is to the northeast and that the angles of the slopes are generally below 40° of declivity; the only exceptions are two or three points where they rise to 50° and at one point on the northern part of the western face where the beds rise to a vertical position. At many points the observer will find steeper dips than those indicated, but on close inspection he will note that the beds have been tilted by irregular slipping. The total thickness of the deposits shown in the Gay Head section cannot be exactly determined, because of the considerable differences in the amount of the dip and the direction of the strike at different points. Making a rough allowance for these variations we find that the total thickness exposed in the section at Gay Head may be estimated at two thousand feet, with a probable error of two hundred feet.

It will be observed, however, that the escarpment at Gay Head exposes only a very small part of the total section of these deposits on Martha's Vineyard. We observe at Gay Head and elsewhere that the prevailing strike of these beds is from northwest to southeast; therefore, as the dip is northeasterly, we rise in the series as we go from Gay Head toward Indian Hill. Between these two points the Tertiary beds are very imperfectly exhibited; enough of them is seen, however, to make it clear that the whole of this district is composed of strata essentially like those shown at Gay Head. In this section, which is about eight miles in length, the dip and the strike are somewhat variable in amount and direction, but hardly more so than in the Gay Head section. If, therefore, there are no repetitions from faults or folds, the total thickness of this series between Gay Head and Indian Hill would amount to at least fifteen thousand feet.

There is no good reason to believe that there is any considerable repetition of these beds by faulting or folding. The very extended exposure at Gay Head, where nearly a mile of section is exhibited, shows no trace of such dislocations. Moreover, as will be seen hereafter, this part of the Tertiary series is certainly of later Miocene or Pliocene age, and there is no reason to believe that the rocks of eastern New England have been subjected to any very great faulting or folding since that time.[1]

The only clearly observed case of folding which is shown in these beds is that which appears in the deposits exposed in the section at Weyquosque or Chilmark Cliffs. At that point we have much the same association of materials as is exhibited at Gay Head. In the latter, as in the former exposure. white sands, yellowish and red clays, and lignites are commingled. The lignites are thinner than they are at Gay Head and the brown, phosphatic deposits are wanting; otherwise the series are essentially alike. As is shown in the diagram (see Fig. 59), the Weyquosque section exhibits a slight but distinct anticlinal axis. I do not think it possible that this disposition of the beds can be the result of any process of deposition. I am, therefore, compelled to believe that the development of this axis is due to mountain-building processes. As the axis is low it does not bring about any considerable repetition of the beds. It is therefore reasonable to suppose that this Tertiary section is tolerably continuous and that

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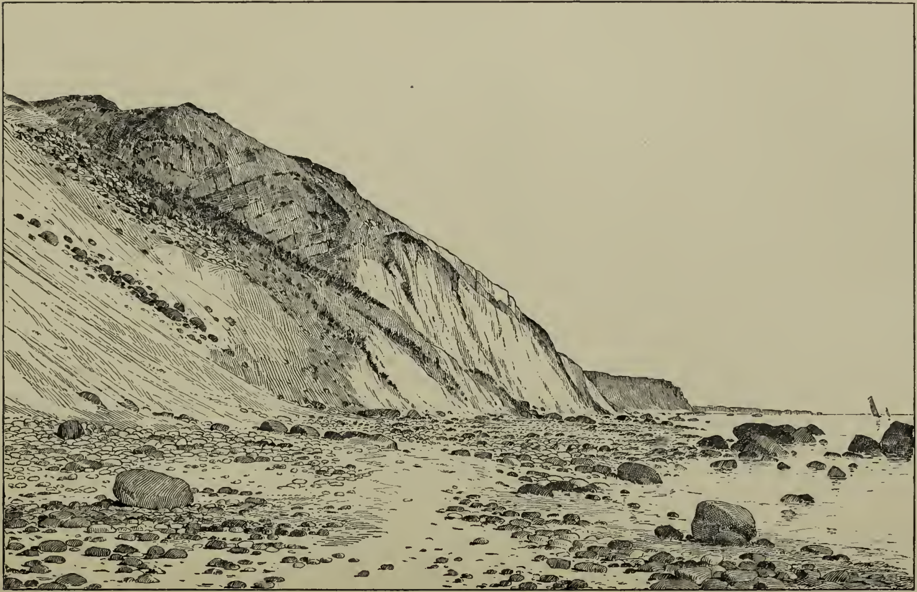
[1] When I first began to study the Gay Head section it seemed likely that the repetition which is evident in the beds there exhibited might be explained by the supposition that they had been faulted or repeated by folding, the faults or the seats of the folds being hidden in the concealed portions of the section or by the numerous slidings which have occurred on the escarpment. However, on careful study of the section I have been driven to abandon these hypotheses and to regard the repetitions in the succession of the strata as indicating a recurrence of similar conditions in the process of deposition.

At a point about seven hundred feet south of the light-house there is reason to suspect the existence of a small fold in the strata. One of the osseous breccias which occur at this point appears, from time to time, as the erosion of the surface favors its exhibition, in the form of a rude, somewhat quadrangular fold. This fold was first observed by Dr. F. J. H. Merrill, of Columbia College. It was very obscurely shown when the section which accompanies this report was made. At the present time, June, 1887, it is again distinctly exhibited. Although it is barely possible that this accident of the strata may be due to some complication of the sliding dislocations which are continually in progress on this escarpment, I am disposed to agree with Dr. Merrill in regarding it as a true fold, though it probably does not lead to any considerable duplication of the strata, for its effects appear to be lost in a certain crushing of the beds on either side of it. It appears to be one of those local accidents which are common in the dislocations of extensive series of beds.



GAY HEAD CLIFFS, SOUTH END.

it contains beds in something like the order in which they are disposed at Gay Head.

It is no easy matter to account for the remarkable thickness of this series. The difficulty is increased by the fact that neither the summit nor the base of this great section is visible, so that there may be several thousand feet of the series unknown to us. It is moreover clear from the general physical constitution of the beds that the whole series must be considered as belonging to one great division of the Tertiary deposits. It is manifestly impossible to suppose that we have here 15,000 feet of strata belonging to one section of the Tertiary when all the beds on the eastern shore of the continent belonging to this age do not aggregate more than one-third of that thickness.

ORIGIN AND NATURE OF THE ROCKS OF THE VINEYARD SERIES.

The only hypothesis which affords any satisfactory way out of the above-described perplexity is the following: We must suppose that the Vineyard section is not a normal, stratified deposit at all, but that it belongs to the important class of cross-bedded deposits, such as are formed by continuously acting and strong currents. In this particular case the deposits were formed at the mouth of a great river. The beds seen in the great section at Gay Head, and probably all those in Chilmark and Tisbury as well, were deposited in succession upon the advancing border of the delta of that stream.

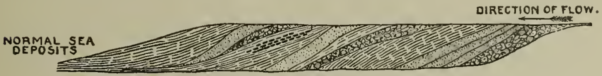


FIG. 60. Diagram showing delta structure.

So little attention has been paid to the phenomena of cross-bedding that it may be as well to explain more clearly what is meant by the term as it is now used. Ordinary beds of stratified rock are commonly deposited in horizontal layers on the bottom of water-covered basins. Such beds may have an indefinitely wide extension: a single layer may often be traced for scores of miles. Such ordinary beds do not begin or end suddenly except with the shore lines. They may change their character, but they may be traced, theoretically at least, as continuous, equivalent sheets, varying only in thickness and in composition across the floor of the seas. Where, however, sedimentary matter is pushed out to sea by a river current, it builds strata in the form of inclined layers on the outer verge of a shelf, as is shown in the diagram (Fig. 60). These layers have a very limited extension in any direction. and therefore they may be accumulated with great rapidity.

During the time required to form 10 feet of normal strata on the bottom of the Gulf of Mexico, for instance, the Mississippi River may project its delta, composed of cross-bedded layers, into that gulf for the distance of several thousand feet. Cross-bedded strata often pass by insensible gradations of slope into normal strata. This is the case as we pass from the marginal portion of the delta toward the deep sea. It is also in part the case within the delta itself, where coarse sediments give place to fine mud. But within the portion of the delta which is covered with salt water even the finest muds are precipitated with such rapidity that they become cross-bedded strata. This rapid precipitation, as is well known, is due to the action of the salt in the sea water.

These considerations make it obvious that if we can prove the Vineyard series to have been deposited at the mouth of a great river we shall thereby avoid all theoretical difficulties arising from the very great thickness of the deposits. Assuming, then, for our hypothesis, that these beds were formed in a delta, we will now proceed to examine into their structure to see how far it is consistent with this view.

The first point to determine in this effort to verify our hypothesis is whether the Vineyard series was deposited on a coast line, for it is evident that unless this can be proved the hypothesis of their delta nature cannot be valid. As far as the Gay Head section is concerned there can be no doubt that all the beds were formed along the coast. This is tolerably well shown by the occurrence of lignite beds in every part of the section, there being no part of it where the beds are quite without vegetable matter for more than five hundred feet. Moreover, the character of these lignite beds makes it necessary to suppose that they were accumulated at the mouth of a river. The thicker beds of this nature are almost altogether composed of woody matter, the only admixture being a little sand and clay. Such deposits are never accumulated on the sea floor. The entire absence of marine fossils from the mass corroborates this conclusion. It cannot be doubted that a small amount of lignitic matter may find its way to the bottom of the sea, but it seems impossible that tolerably thick beds of purely woody matter derived from the land could ever have been formed on the floor of the open sea. It is also impossible to believe that such beds of lignite could have been accumulated in the alluvial terraces at any considerable distance from the shore line. The only place where lignitic deposits, such as we find here, can be formed, is in the swamps at the very mouth of a considerable river, that is, in a delta.

There is other evidence to prove that these beds were laid down in a delta deposit. In the southern part of the section there are several thin layers of coarse conglomerate. The pebbles of these beds are mostly composed of quartz, but there are some fragments of syenite and other hypogene rocks among them; at some points these pebbles form an irregular bed lying nearly horizontally on the surface of the steeply inclined strata; a little farther on they may be observed forming a bed between the two adjacent members of the cross-bedded deposits (Fig. 61). This peculiar arrangement can only be explained by the supposition that we have in the horizontal portion of the conglomerate the part laid down by the stream on its bed; in the inclined part, the portion which was laid down on the advancing front of the delta.

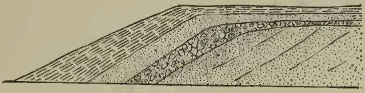


FIG. 61. Diagrammatic section of interbedded and overbedded conglomerates at Gay Head.

Still further evidence as to the delta nature of these deposits is afforded by the wedge-like shape of certain beds. They run out within a short distance, often within a few feet, of their origin, as is shown in the general section of Gay Head (see Pl. XXVI). This is thoroughly consistent with the nature of delta deposits, but not so with that of those formed in any other way. We also remark the fact that the beds vary much in their inclinations, the coarser materials forming steep frontal slopes, and the finer, slopes of less inclination. Still further we note that the beds of coarse materials often have within themselves a slight cross-bedding. This is observable only in the whitish sands and is not at any point very distinct or continuous. This structure, probably arising from whirling currents, is consistent with the processes which form shore deposits by the aid of tidal currents alone, but it is also quite reconcilable with the theory that this deposit was formed in the delta district of a large river.

The foregoing considerations lead us to the conclusion that the hypothesis of the delta origin of the Vineyard series is essentially verified. We may thus feel satisfied that we have here deposits formed with great rapidity by a large river of the Tertiary age. We will now endeavor to determine something about this stream, as to the direction of its flow and the origin of its peculiar sediments.

The general slope of the beds of the Vineyard series is toward the northeast. This is clearly the case in the district about Gay Head, but less clearly so in the Chilmark district, where the strike is somewhat variable and obscurely shown. There can be little doubt that the general course of the stream, which I shall hereafter call the Vineyard River, was from the westward. It should be noticed that the direction of the dip of the beds formed in a delta does not afford any precise indication as to the course of the stream even at its mouth; the successive débouchures may point in directions which vary greatly from that of the main stream. An inspection of the present delta of the Mississippi or of that of any other great river will make this point clear.

It is evident that this delta must have been formed by a river of large size or by a number of streams debouching in a common delta. The area occupied by the beds on Martha's Vineyard, provided we assume that they underlie the whole of the island, is larger than the delta of any existing river on the Atlantic Coast. The extent of the beds of coarse sediment on the front of the delta is a proof that the stream was one of much power. No such accumulations are making on the front of our rivers on this part of the Atlantic Coast.

We have now to consider the origin of the sediments which compose the Vineyard series. Our principal point will be, if possible, to determine the portion of the land area whence they came. It may be well to say that the existing surface of New England has retained its present lithological character from a very early time. The pebbles of the Roxbury conglomerate, a deposit of Cambrian age extensively developed near Boston, Mass., closely resemble those of the glacial till in the same region, so little has the general mineral character of the district changed during this vast time. In the Narragansett basin the millstone grit and in the Connecticut Valley the Triassic conglomerates exhibit the same likeness to the beds of pebbles formed during the last ice age. It is therefore evident that we may expect in this search to find no great difficulty arising from changes in the geology which have taken place since Tertiary time unless it arise from the stripping away from this surface of beds of relatively modern formation.

Taking the beds of the Vineyard series in the order of their importance, we shall first consider the deposits of white sand. As before stated, these beds are composed of materials which were derived from the breaking down of granitic rocks. All we know of the structure of this part of New England leads us to suppose that the prevailing rock in the immediate vicinity of the delta is of this nature. The nearest bed rock on the mainland, if comminuted, would yield a material similar to this white sand. The difficulty is to see how such a vast quantity of this granitic material could have been rapidly eroded and brought into the channels of a river unmingled with other forms of detritus. The only way in which we can hope to throw any light on this problem is by comparing these deposits with similar ones whose history is better known to us.

There is a parallel case in which large amounts of detritus derived from crystalline rocks have suddenly been precipitated into the sea, i. e., the millstone grit. The beds of this deposit, especially in the region west of the Blue Ridge, in Kentucky and Tennessee, closely resemble those we are now considering. I have elsewhere endeavored to show that this deposit may be explained by supposing that the crystalline rocks of the Blue Ridge, having long been subjected to atmospheric decay, were suddenly exposed to powerful erosion such as would come from the action of a glacial sheet and the decayed rock matter was thus given to the sea.[1]

I venture to suppose that such accumulations of detritus may have been formed at other periods along our New England shore whenever, after long-continued decay, the rocks were exposed to powerful erosion either by glacial action or by the waves of the sea during a period when the surface of the land was sinking. The great difficulty is to account for the exclusion of other sediments from these white sands during the process of erosion and deposition. This exclusion of other sediments may be explained by the supposition that the deposits were formed during a period of subsidence near the line of a shore presenting cliffs of extensively decayed, granitic rocks. At first I was disposed to take this view of the origin of these deposits, but the frequent occurrence of lignites and clay beds with them seems to demand the delta theory. We may reasonably suppose that the Vineyard River had several branches, or rather that there were several rivers terminating in one delta, and that one of these branches drained a district underlaid altogether by rocks which yielded these whitish sands. Furthermore, whenever the changes in the outlets brought the detritus from this valley to a particular part of the delta to the exclusion of materials from other adjacent streams these white sands were formed. It should be said that the extreme whiteness of these sands is superficial and arises from the decay of the material, especially feldspar, which they contain. A few feet below the surface they have the hue of ordinary granitic rock.

The deposits of reddish sand and clay next deserve attention. These are necessarily to be explained by the same hypothesis as that by which we account for the white sands, i. e., by the supposition that they were derived from a region where reddish sandstones and shales were exposed to decay. We naturally turn to the Connecticut Valley as the probable source of materials of this nature. As is well known, the Triassic rocks of that valley have a prevailing red hue, and if they furnished the detrital materials for the Gay Head deposits their color and composition would be sufficiently accounted for. It would be obviously impossible to have these bright red clays and sands derived from the Connecticut Valley as it is at present constituted, for the reason that the red beds occupy only a small part of its surface and the detritus borne out from it is a mixture of materials from many different kinds and colors of rocks. But it is evident that the Triassic rocks of this valley have been very much diminished in area in recent geological times. These deposits occur in thin sheets over a large part of the field now occupied by them and they were very extensively worn away during the last glacial period.

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[1] See Glaciers, by Shaler and Davis, p. 97; also, Reports of Kentucky Survey, new series, vol. 3, pp. 186–188.

It is reasonable to suppose that they may have covered the whole surface of the valley during the middle Tertiary period.

Thus on a priori grounds it seems not impossible that the detritus composing these red beds of Martha's Vineyard may have been derived from the region of the Connecticut Valley. When we examine the sediments themselves we find that they afford what may be taken as confirmation of this hypothesis. They contain numerous fragments which appear to be essentially like the red sandstone of that valley and infrequent small fragments of reddish slate which may also have been derived from that district.

There are, however, some objections to this hypothesis. In the first place, it requires us to suppose an extensive area of Triassic deposits in the upper Connecticut Valley or else a narrower limitation of its basin in former times than we may be justified in supposing. Moreover, from Gay Head to the existing deposits of Triassic age above the level of the sea there is a distance of over eighty miles and we have no evidence that the beds of that age exist in the intervening district. Manifestly the alternative is to suppose that during the time when these deposits were forming there were extensive areas of Triassic rocks nearer this district than the Connecticut Valley. It is by no means improbable that the Narragansett basin—i. e., the region now occupied by the valleys of the Taunton and Providence Rivers and their tributaries—may have been covered with Triassic deposits down to a recent time and that the red materials of the Miocene deposits came from that district.

This hypothesis finds some confirmation in the existing conditions of the region about the head of the Bay of Fundy. In that part of the shore there are extensive escarpments of Triassic sandstones and shales essentially like those of the Connecticut Valley. These beds are now yielding sediments which have much the color of the red clays and sands of Gay Head. If we had had a large river in that district which in its times of flood brought down great quantities of reddish mud and another stream, whose sediments were derived altogether from granitic rocks, discharging into the same delta, the changes in the points of discharge of these two streams might produce a distribution of sediments such as we find in the Vineyard series.

It will be observed that in the highest part of the Gay Head section the characteristic red clays and white sands are to a great extent replaced by ferruginous, brownish-colored sands, as before described. These beds appear to be more nearly in the nature of the ordinary delta accumulations such as are forming at the mouths of our southern rivers than the lower lying strata of this section. They not only contain a considerable variety of nodules and broken bones, but the general constitution of the beds has a more familiar aspect than the red and white sands in the lower part of the section.

One of the most remarkable features connected with the Gay Head section is the distribution of the beds of bowlders which are found in certain of its strata. These layers of bowlders are irregularly distributed; they are in the main confined to parts of the section where the white sands are found, but they occasionally occur also in the form of isolated bowlders scattered through the red clays. By far the greater part of the pebbles are of quartz and the fragments are much rounded; the other hypogene rocks of the mainland are represented by pebbles which are generally much decayed. At two or three points in the lower part of the Gay Head section these pebbles form thin sheets of conglomerate disposed as shown in Fig. 61. In these pebbly beds the mass commonly has a beach-like structure and in two of these conglomerates there are occasionally sharks' teeth. It is not certain whether these teeth have been transported from some pre-existing bed or not, but their delicate structure makes it appear most likely that they are indigenous to the deposit.

The quartz pebbles of these conglomerates are probably remnants of veins which existed in the granitic rock whence these white sands were derived. As is well known, such quartz veins resist decay much longer than the rocks in which they are found and when the decayed mass is broken up by erosive agents they form pebbles, while the remainder of the mass is reduced to the state of sand or clay. There can be no doubt that the quartz pebbles of the millstone grit of eastern Tennessee and Kentucky had this origin.

Besides these layers of quartz pebbles there are occasionally large masses of sandstone, generally of a dark-red hue, which occur as isolated blocks and so far as observed only in the red clays and sands. These fragments are generally subangular in form. The largest I have seen contained about ten cubic feet. It seems necessary to believe that they have been borne to their places by floating ice. As there are no traces of vegetable matter in these clays it seems unreasonable to suppose that these great erratics have been transported to their place in the roots of trees; moreover, the size of the largest fragments would make it improbable that they should be so carried.

It will be noted that the numerous beds of lignite indicate that the neighboring land was, from time to time at least, the seat of an abundant vegetation while these beds were depositing. The entire absence of vegetable matter in the intermediate portions of the section is a very singular feature. It appears as if these beds had been formed at a time when the land was alternately the seat of an abundant vegetation and quite destitute of such a covering. This sharp contrast in conditions is paralleled in the period of the Coal Measures and less distinctly in the time of the last glacial period. In those stages of the earth's history we have like sudden alternations from organic to inorganic conditons.

This absence of organic life characterizes at least nineteen-twentieths of the total section of the Gay Head series. The red clays and the white sands are quite without fossils except where a thin bed of lignite occurs. The lignites in these beds are always definitely limited; in no case are the fragmentary vegetal remains scattered through the section. The limitation of the fossil animals is almost equally definite. They are found only in the layers indicated in the diagrammatic section or in half a dozen beds having a total thickness of less than two hundred feet.

In the usual conditions of any land surface it could not yield sediments such as those we find in the white sands or the red clays of the Vineyard series. These beds would inevitably have been discolored by the soil waste which in a normal river would have constituted a large part of the sediments it bore to its delta. The only way in which I have been able to conceive the formation of deposits so entirely free from admixture of soil is as follows, viz: Let us suppose in the first place that the rocks of the region from which these sediments came had been deeply decayed, as we now find them decayed in the southern part of the Appalachian district, where the ice of the last glacial period did not operate as it did in the northern parts of the continent. If, after a long period of exemption from ice action, we should have a glacial sheet imposed upon the surface, the result would be that the decayed rock, without admixture with any solid material, would rapidly be conveyed to the streams and by them borne to the delta. In the temporary retreats of the glacier we should have the surface of the land recovered by forests which would yield the abundant vegetal detritus composing the lignite beds.

In Europe we have some evidence of the existence of a wide-reaching glaciation in the Miocene period. It is therefore not unreasonable to suppose that such conditions may have existed on this continent in the same age.

DEPOSITS OF DOUBTFUL AGE.

There are two sets of deposits on Martha's Vineyard, the relations of which are not as yet determined. One of these is the Weyquosque series before mentioned; the other, the hidden series, which is only certainly known from the drift in the district about Indian Hill and on the shores of Cotamy Bay.

The Weyquosque series, as before remarked, is of doubtful age, with the probabilities inclining towards the conclusion that it overlies the Vineyard series and is of later Tertiary age. If it be of this period and if, as is likely, it shared in the disturbances which have dislocated these beds, it is to be taken as evidence that the mountain-building movements continued to a later time than would be indicated by the Vineyard series alone.[1]

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[1] At the southern end of Sengekontacket Pond, immediately south of Cottage City, there is a small area in which occur beds which probably belong to the same age as those at Weyquosque. The exposure is quite superficial, and, though the physical resemblance to the materials composing the deposits is great, I hesitate as yet to class them as of identical age.

It is clear that the Weyquosque series represents erosion from another district than that which furnished the sediments of the lower-lying beds. In it we find no trace of the red and white sands or of the lignites which characterize the Vineyard series in such a remarkable manner. The section, though exceeding fifteen hundred feet in thickness and possibly over two thousand feet thick, is composed of gray and blue clays and whitish sands, the latter sometimes containing a few rounded pebbles of hypogene rocks. For the present its position must be left undetermined. There are reasons to suspect that it may be of the same age as the lower clays on Nantucket and on No Man's Land, and possibly certain others in Duxbury and at other points in the Cape Cod district.

The other and less known series is shown only by the abundant fragments of its beds contained in the glacial drift in the region about Indian Hill and the rarer fragments which are found on Chappaquiddick Island and the neighboring shores of Cotamy Bay. These fragments, which on certain fields about Indian Hill constitute a large part of the glacial detritus, are the waste from deposits of highly ferruginous sandstone, often taking on the form of an impure, siliceous hematite. The strata whence they were derived were thin-bedded and abounded in obscure fossils. The angular form of the fragments and their relatively large size, notwithstanding the fact that the rock is quite friable, shows that they cannot have been transported more than a few hundred feet from their original position.

Although the fossils of this hidden section are very abundant, they are extremely altered by the introduction of the iron oxide which evidently replaced the lime of the fossils. These fossils, so far as determinable, are all of molluscan types, except a few fragments which may be those of crustaceans, and it is doubtful whether any of them are of the same species as those from Gay Head. They include an oyster of exogyron aspect, a pecten of the costata type, as well as several other forms. The general aspect of these fossils (in all, about a dozen species) leads me to believe that they are of a decidedly older age than those found in the Gay Head section; that they are at least as old as the Lower Cretaceous and may be yet older.

It is a difficult matter to determine with accuracy the areal distribution of the Weyquosque series on the surface of Martha's Vineyard. The materials of which it is composed are of a very yielding nature, and where scarfed by the sea they are apt to be covered by the glacial materials which fall from the upper part of the section. Besides the localities already noted, this deposit, as is shown upon the map, is more or less clearly exhibited at three other localities on the shore of the island. One of these is at the mouth of the brook on which are situated the old brick kilns which are a conspicuous feature on the northern shore of the island. One other lies at a point on the north shore about half a mile west of that brook. Between the last-named locality and the mouth of the brook there is a considerable exposure of the Gay Head series. About three hundred yards east of the brickyard is another considerable exposure of the Weyquosque deposits. All three of the localities on the north shore have the same essential character as the great section at Nashaquitsa. The clays have an earthy or soil-colored look, though they contain no evident plant remains. The bedding is very indistinct and it appears to have been to a considerable degree affected in a local way by the pressure of the glacial sheet against this part of the shore. The beds, so far as their position can be determined, strike in a general northeast and southwest direction and lie at very high angles.

As is indicated by the map and the foregoing conditions, the Weyquosque series is evidently distributed in such a manner as to make its relation to the Gay Head series tolerably plain. Except in the trifling exposure just south of Cottage City the beds of this age have not been found far away from exposures of the Gay Head series, and even in the locality last referred to it seems likely from the waste of the Gay Head series contained in the glacial deposits that the beds of that age lie near the locality in question. This feature in the distribution of the Weyquosque beds seems clearly to establish the fact that they are related in age to the Gay Head deposits rather than to those of the glacial period.

It is a remarkable fact that the deposits of this last-named series, though very thick and apparently well suited for preserving fossils, have afforded no organic remains of any description. In their non-fossiliferous character they closely resemble the Gay Head series. We have already noted the fact that the pervading lack of fossils in the deposits at Gay Head may most easily be explained on the supposition that they were formed during the glacial period. It may well be that the non-fossiliferous character of the Nashaquitsa deposits can be accounted for in the same manner.

The recent examination which I have made of the island of Naushon, one of the Elizabeth Islands immediately northwest of the island of Martha's Vineyard, has shown me that the greater portion of that island is composed of a mass of yellowish and reddish, stratified sands containing occasionally water-rounded pebbles. The surface of these great arenaceous deposits has been worn into the form characteristic of glacial erosion. On this surface lies an irregularly disposed sheet of till and kame deposited during the last ice age. It is evident on even a casual inspection that these sands of the Naushon series are not in a strict sense of glacial origin. They appear to antedate the time when the ice sheet was first imposed upon this surface, though they may perhaps represent the deposits made in some one of the interglacial periods. After becoming familiar with the aspects of these deposits on Naushon I searched for them on the island of Martha's Vineyard. I found that although they are not abundantly developed on the last-named island they are noticeable in several of its coast sections. They appear with variable thickness above the level of the Nashaquitsa series in the cliffs which bear that name. They are also imperfectly shown at various points on top of the Gay Head series within a few hundred feet to the north and south of the light-house on that promontory. They are also imperfectly shown in the sections along the north shore. I am inclined to believe that the deposits of this series will be found on Cape Cod, but it is clear that they are generally wanting beneath the glacial deposits on the other portions of the mainland.

Although for the present I must leave the precise age of these deposits undetermined—and, indeed, it must remain doubtful whether or not they belong to the glacial period—there are several reasons which lead me to suppose that they altogether antedate the coming of the ice sheet of the last glacial period to this part of the shore. I am also of the opinion that they are not in any way related in age to the beds of the Gay Head or the Nashaquitsa series. They clearly lie in unconformable attitudes on the eroded surface of both those series of deposits. The circumstances of their distribution point to the conclusion that they are in age most nearly related to the deposits of glacial age. On the island of Naushon I have observed that while the deposits which unquestionably belong to the glacial age abound in grains of magnetic iron ore such magnetic material is entirely wanting in the underlying orange-colored sands, though these beds contain a noticeable quantity of ferruginous matter in a highly oxidized form. As I propose to make these deposits of yellow sands the subject of a special memoir I shall not give them further consideration in this report.

DISLOCATIONS OF THE VINEYARD SERIES.

We turn now to the consideration of the disturbances which have affected this series of beds since the time of their formation. At first it seemed to me that the inclination of the beds might be merely the original inclination of the deposits as they were formed on the advancing front of the delta. A further study of the facts has shown that this hypothesis is untenable for the reasons given below.

The deposits formed on the frontal apron of a delta, though they incline toward the sea, are never placed at anything like the angle in which these Gay Head beds lie. The steepest slopes on the front of existing marine deltas where the tides operate do not exceed 5° of declivity, though in the case of débris formed in great lakes they may have considerably greater slopes. The average inclination of these Gay Head beds exceeds 25°; at several points it amounts to as much as 45°, and at one point the beds are vertical (see Pl. XXVI). These steep dips are sufficient to prove that the beds have undergone a considerable dislocation from their original condition. They also indicate that the amount of this dislocation has varied very much in different parts of the section.

As the occurrence of considerable dislocations in this district since Miocene time is a fact which goes against the prevailing opinion of the history of this part of the continent, it has seemed to me necessary to consider whether any other cause than mountain-building forces could have brought about this tilting of the rocks.

There appeared to be but two causes, other than the action of mountain-building forces, which could by any chance have brought about the dislocation of the beds. One of these is the slipping of the beds from the undermining action of the sea. Though this cause is doubtless effective in producing many small crumplings and tiltings of the large wedges of detached material which are on their way downward toward the sea, it cannot be held to have operated in the evidently firm-set face of the cliff. Moreover, despite the imperfect nature of the exposures in the inland district of the island, these beds are seen to have steep dips everywhere, and at the Weyquosque section they form a distinct anticline. This suggestion may therefore be dismissed without further consideration.

It has often been noticed that where a glacier has pressed against stratified clays and sands these strata are much flexed, having been crumpled by the great pressure which the ice has brought to bear upon them. Nor is this action of the ice altogether limited to yielding strata. Where slates stand in a vertical position with the strata at right angles to the direction of the glacial path, their beds are sometimes bent or broken and the ruptured fragments turned southward. An excellent example of this action is shown in the slate quarries in the Massachusetts field, at Quincy. In other countries geologists have observed similar instances of dislocated strata which they have ascribed to the action of glacial ice.[1]

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[1] Since the pages of this report have been in press I have had an opportunity of conferring on the ground with Dr. F. J. H. Merrill, whose paper in the Annals of the New York Academy of Sciences, vol. 3, Nov. 7, 1884, p. 341, entitled "On the geology of Long Island," has called attention to the effect of glacial action in dislocating pre-existing, incoherent, stratified deposits. The result of this conference has been to convince me yet more firmly that the beds exhibited at Gay Head and at Nashaquitsa cannot have owed their dislocation to the action of the glacial thrust, for the following reasons: First, the pressure exercised by the glacial movement can operate only upon the superficial portion of the ground over which it slopes; it is impossible to conceive that the thrust can be propagated in an effective manner through great thicknesses of deposits which have the incoherent nature characteristic of all the stratified materials found on Martha's Vineyard; secondly, the peculiar position of the axes of the anticlines exhibited by the Tertiary section on Martha's Vineyard requires us to suppose, in case we adopt Dr. Merrill's hypothesis, that the thrust which produced the dislocation was brought about by peculiar converging tongues of ice, and not by the direct thrust of the main glacier operating in the general axis of its motion.

While rejecting the hypothesis of ice thrust as the source of the principal disloca-

On careful examination it becomes clear that the glacial ice had no influence in producing the dislocations of the Vineyard series. This is shown by the fact that these beds have a dip toward the northeast, a direction which is at right angles to the course of the glacial stream. Even were the dip of these beds coincident with the course of the glacier we should be compelled to reject the hypothesis that they were flexed by its pressure, for the reason that a tolerably uniform inclination in a section of such great thickness could not be brought about by such action. It is equally impossible that it could have produced the Weyquosque anticline. On this account I shall omit further discussion of the hypothesis.

We therefore turn, with the assurance that no other cause will suffice, to the ordinary cause of such dislocation, i. e., the mountain-building forces. I confess it is with some surprise that I find it necessary to assume the occurrence of considerable disturbances in this district in a time which we must place later than the close of the Miocene period. But the evidence is clearly sufficient to prove that in this region important movements have taken place since the close of that period. It would be of the utmost importance to determine the precise time at which these dislocations took place. This seems to be impossible. The only point which we can make clear is that, after the deposition of beds which certainly were laid down as late as the Middle Miocene and before the close of the glacial period, a series of disturbances took place which greatly dislocated them. That the disturbances occurred before the close of the glacial period is shown by the fact that the upturned edges of these beds were worn off by the glacier. That the dislocation occurred some time before the last ice period began is rendered probable by the fact that this mass of beds which underlies the townships of Gay Head and Chilmark appears to be the eroded remnant of a much larger area, and this erosion, from the nature of its effects on the contour of the surface, could not well have been brought about by ice action, though it perhaps may have occurred during the recessions of the ice which we know to have taken place.

The direction of the compressive movement which produced these dislocations next deserves our attention. This is hard to determine. When beds originally horizontal have been dislocated by a single movement the direction of this movement is easily ascertained, but, where beds have an inclination before the movement takes place, the resulting attitude depends on the direction in which they originally

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tions exhibited on this island, I am disposed to agree with Dr. Merrill in his view that a certain part of the disturbances in the beds exposed on the north shore of the island may be due to the pressure of the glacier. The action of this pressure is most likely the cause of the steep dips and the general disjointed nature of the strata belonging to the Gay Head and the Nashaquitsa series on the shore between Menemsha Bight and the mouth of Roaring Brook.

sloped, as well as upon that of their last movement. This point is commonly neglected in geological inquiries which concern the attitudes of dislocated strata ; from this neglect many serious misapprehensions have arisen. We must therefore state the conditions of the problem.

If the compressive forces act so as to dislocate the beds in a direction at right angles to the strike it is easily seen that the effect will be to diminish or to increase the dip of the beds. If, on the other hand, it act in other azimuths, it will tend to change the direction of the strike to an amount determined by the ratio of the original to the succeeding dip of the beds. Thus, beds originally striking north and south at an angle of 10° to the horizon, and subsequently tilted by a force which in horizontal beds would produce an east and west strike of 10° of declivity, would have the resulting strike line in a northeast and southwest direction. It is evident that the direction of the strike will depend upon the amount of the dip in the first and second states of the position.[1]

The sections obtained on the island, except those at Gay Head and Weyquosque Cliffs, are extremely imperfect. So far as they go they appear to indicate that these deposits of the Vineyard series are generally arranged in a continuous, monoclinal form, much as they are at Gay Head, the Weyquosque anticline, though of great theoretical interest, being of small structural value. It is manifestly probable that these dislocations were cast in the form of anticlines and synclines rather than in the form of a monocline, as the last would require either a profound fault or an inconceivable tilting of this portion of the continent.

The pressure which produced these dislocations probably operated so as to produce folds extending in a northwest and southeast direction. This is fairly proved by the anticline of the Weyquosque section.

Before we leave this part of our subject it is worth while to notice the fact that the recognition of a system of mountain axes involving the Tertiary beds of Martha's Vineyard and vicinity may aid us to explain the general geology of this district. It may, for instance, ac-

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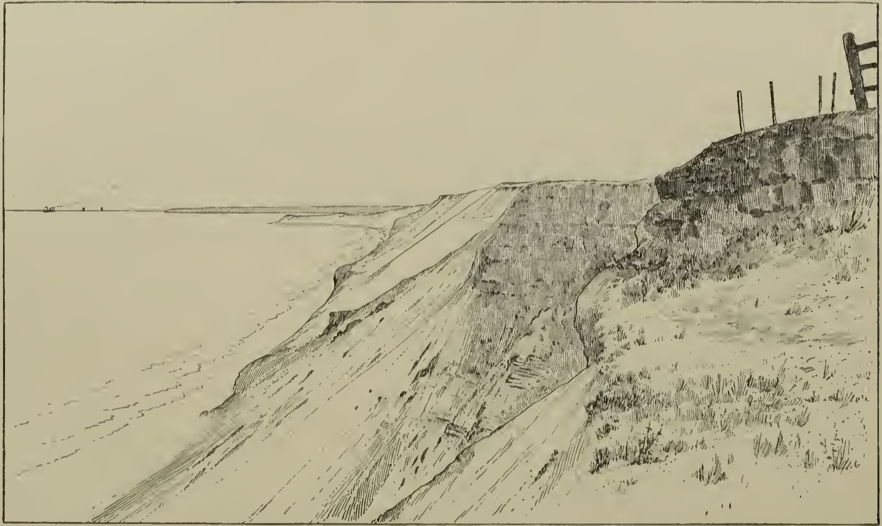
[1] Unfortunately there is no certainty as to the original direction of the dip after it has been compounded with the second dislocation. It may be said, however, that the less in amount the original inclination the less it will account for in determining the final attitude of the beds. There is thus a chance of determining the original strike of the beds by ascertaining the variations existing in the azimuth of the same bed at points where it has great differences in inclination; for it is manifest from the foregoing consideration that where the original dip was 5° and the secondary dip at some points 20° and at other points 80° it may be possible by comparing the azimuths to determine the original dip. I have tried to apply this principle to the Gay Head section, but I find that at this point the strikes are gradually turned from a nearly east and west direction in the southern end to a nearly north and south direction at the northern end of the cliff, and that this change takes place in an irregular manner, making it quite impossible to use the method above suggested.



WEYQUOSQUE OR CHILMARK CLIFFS, LOOKING SOUTHWEST; NO MAN'S LAND IN THE DISTANCE.

count for the existence of an isolated mass of drift in the island of No Man's Land. It is hardly possible to account for this solitary mass of kame and terrace drift by the supposition that it owes the whole of its relief to the morainal matter which is exhibited on its surface; for it is not continued even by shallows to the east and to the west beneath the level of the sea. If we may suppose that it is a fragment of a Tertiary axis upholding a portion of the drift sheet, its isolated character would be sufficiently accounted for. So, too, the island of Nantucket, which is not easily explained as a drift-heap alone, may rest upon the remains of an anticline which was formed during its period of dislocation. This theory will also aid in explaining certain peculiarities of Cape Cod which cannot be accounted for on the supposition that they are mere accumulations of drift.

It would be interesting to inquire whether there are elsewhere indications of mountain-building movements which may be referred to this geological period, but such an inquiry cannot properly be undertaken in this memoir. So, too, the detailed discussion of the orographic features of these deposits must be postponed for the reason that they should be considered in connection with the general geological history of the district in which they lie.

POSTGLACIAL EROSION OF MARTHA'S VINEYARD.

The general surface of Martha's Vineyard has been exempt from any considerable erosion since the close of the glacial period, as is shown by the unchanged condition of the moraines and delicately molded kames, as well as by the preservation of the faint channels excavated in the terrace drift or plain region in the southern part of the island. The shores of the island, on the other hand, have been greatly eroded by the action of the sea waves and the tidal currents which sweep by its coast (see Pls. XXV, XXVII, XXVIII, and XXIX). The amount of this erosion is very different on the northern and on the southern shores. The southern coast is exposed to the wide ocean, the northern meets only the waves of Vineyard Sound and Nantucket Bay.

The rate of erosion on the southern coast of the island varies much in different places. From Gay Head to Squipnocket Point there seems at present to be little erosion going on, nor is there any evidence that much wearing has occurred in this section of the shore since the close of the glacial period. This is doubtless due to the fact that, owing to the regimen of the currents, the sands accumulate on this shore. From Squipnocket Cliff to the eastern end of Nashaquitsa Cliffs the erosion is exceedingly rapid (see Pl. XXVIII). From Nashaquitsa Cliffs to the eastern extremity of the island the inward movement of the shore may on the average be less rapid than in the last-mentioned section, but it is still tolerably speedy.

Prof. H. L. Whiting, of the U. S. Coast Survey, has ascertained that in forty years, i. e., from 1846 to 1886, the shore in the central part of Nashaquitsa Cliffs moved into the land 220 feet, or at the average rate of about five and one-half feet per annum — perhaps the most rapid gain of the sea on the land where the shore is considerably elevated which has been observed on any part of the New England coast. This swift invasion of the sea is the more remarkable from the fact that these cliffs of drift material contain large bowlders which we might suppose would have accumulated on the beach in front of the cliff and thus have restrained the action of the waves; but, though quantities of these great bowlders are annually precipitated upon the shore, they quickly sink into the sands, leaving the face of the cliff open to the assault of the waves. The detritus from these cliffs travels to the eastward and finally finds its way to the eastern face of the island, forming the extensive shoals and beaches in that district. This rapid movement of sands is particularly well shown on the beach south of Cotamy Bay. As before noticed, this bay has from time to time a southern outlet. This outlet appears always to open just south of that part of Cotamy bay known as Mattakeset Bay. As soon as an opening is formed the sands from the west encroach on its westward side, causing the tidal current to wear away the eastern boundary of the channel. In this way the opening is crowded to the east toward Chappaquiddick Island. Finally it is driven against the southern part of that island, where it can no longer move eastward, and is finally attacked by some heavy storm, so that at a time of low tide it is entirely closed (Fig. 62). This eastward movement of the sands affords a tolerably good measure of the rate of erosion on this coast.

The recession of the southern coast east of Nashaquitsa Cliffs is as clearly proved as that of the cliffs themselves. There is a well founded tradition that one hundred years ago it was possible to skate from Tisbury Pond to Edgartown village along the line of connected bays which are now separated from one another. From the existing contour of the shore it would seem as if this would indicate a recession of the coast amounting to at least one-fourth of a mile within that time.

The beach at Cotamy Bay separating its waters from the sea has of late years moved swiftly to the north. Prof. H. L. Whiting found that in twenty-five years, or between 1846 and 1872, it retreated a distance of 450 feet, or at the rate of 18 feet per annum. About the same rate of retreat was observed for a mile or more to the east of Mattakeset Bay.[1] It should be observed, however, that this retreat has been complicated by the movement of a barrier reef of sand encroaching in areas of shallow water, and not by the erosion of an actual shore line. In the retreat of such a beach the

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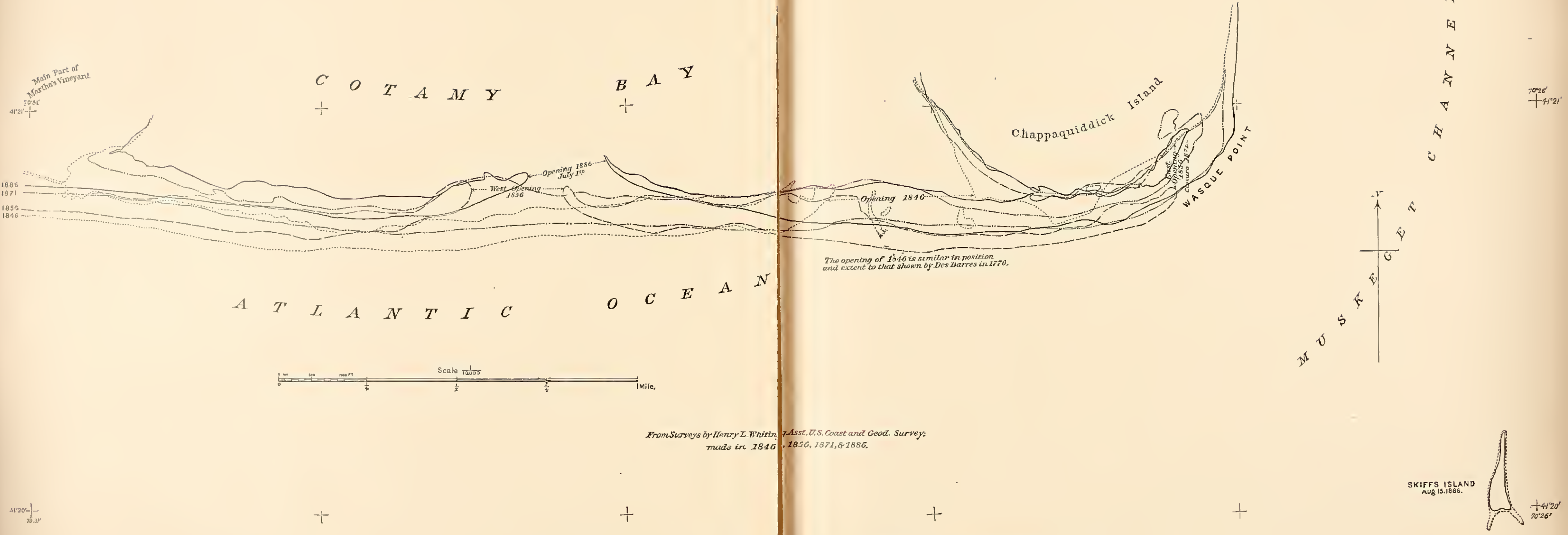
[1] See Seventh Ann. Rept. Harbor Commissioners Boston, 1872, p. 106.



The opening of 1846 is similar in position and extent to that shown by Des Barres in 1776.

From Surveys by Henry L. Whitin Asst. U.S. Coast and Geod. Survey; made in 1846 , 1856, 1871, & 1886.

Fig. 62. Map showing the recent changes in a part of the southern shore of Martha's Vineyard.

movement is in greater part caused by the sand being impelled from the front of the beach over its crest, the movement resembling the motion of a sand dune. It is therefore quite different from the erosion of a sand cliff, where the débris has to be removed from the point where it was formed either laterally along the shore to some place of deposit or outward into the deep sea. Either of these last-named movements may require the transportation of the sand to very many times the distance it travels when it is simply thrown over the beach. It seems to me, therefore, that, from these irregularly shifting sands, we cannot form any conclusions as to the rate of actual erosion on this part of the coast.

If we protract the gradual surface slope of the southern drift terrace seaward we find that it cuts the sea-level at a point about three miles to the south of the present shore. It is therefore difficult to believe that since the island had its present attitude as regards the sea-level the shore could have a greater extension in that direction, unless, indeed, there was another line of moraines to the south of this island. At the present rate of erosion, assuming it to be as much as one-fourth of a mile in a century, this would allow but 1,200 years for the erosion from the original shore to the present line of the coast.

On the eastern side of the East Chop, facing the rather broad waters of Nantucket Sound, the process of erosion is rapid. Professor Whiting found that this bluff, which has a height of about forty feet and a length of about forty-five hundred feet, retreated 75 feet between 1845 and 1871, or at the rate of about three feet per annum.[1] In these years about thirteen million cubic feet of matter has been removed from this section. A portion of it—how large a portion the distinguished observer hesitates to say—has been borne into Vineyard Haven. The West Chop, or western horn of Vineyard Haven, has also wasted in a similar manner, though not to so great an extent. The débris from this part of the shore passes westward and is deposited on the beaches between the West Chop and Tashmu Pond.

On the northern shore west of the West Chop of Vineyard Haven the rate of erosion cannot be anything like as great as it is on the southern coast. It cannot well exceed a few feet in a century. It is doubtful if on the average it amounts to five feet in a century. On this coast the bowlders plentifully accumulate along the beach and defend it from the relatively slight waves of the inland waters which it faces.[2]

The question naturally arises, Has this channel between Martha's Vineyard and the mainland been excavated by the action of the sea since the glacial deposits were formed? There can be little doubt that the island of Martha's Vineyard has been connected with the mainland since the close of the glacial period. The animals and plants of the island are in no way peculiar. There are a few species existing on the mainland which are not found on the island and none on the island which are altogether limited to it. We can hardly believe that several large-seeded plants and many of the land animals have found their way across the five miles of water which separates the Vineyard from the continent.

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[1] Seventh Ann. Rept. Harbor Commissioners Boston, 1872, p. 112.

[2] See appendix (p. 361), containing a report of the results of Professor Whiting's recent surveys, which was received as this memoir was going to press.

As we cannot well explain the formation of Vineyard Sound by the action of waves and currents alone, I am disposed to believe that the original connection of the island with the mainland was due to the fact that at the close of the glacial period this region was considerably higher than it is at present. It is true that we can only prove a subsidence of about ten feet since this postglacial elevation, but as will be seen from the report on the island of Nantucket there is reason to suspect a much greater subsidence of this region. It is to be observed that the channel between Martha's Vineyard and the mainland does not exceed seventy-five feet in depth.

On the western end of the island at Gay Head there is evidence of extensive erosion since the close of the last glacial period. This evidence consists in the waste of the eroded cliff which lies as a platform just below the level of high tide, extending for a distance of a mile from the present escarpment. As will be observed by the soundings on the Coast Survey maps, this terrace plunges abruptly into tolerably deep water. This shelf forms a rude triangle, the base resting on the front of the existing cliff and the sides protracting the line of the shore. There can be no doubt that it affords an approximate horizontal plan of the original outline of these Tertiary deposits as they were left at the close of the last glacial period. The bowlders that constitute this apron have, by the support afforded by the platform of Tertiary beds on which they lie, been kept from the submergence in the sand which has overtaken those that have fallen to the foot of Nashaquitsa Cliffs.

It seems clear from the evidence that the recession of this part of the shore which has taken place since the glacial period amounts to a distance of about one mile. At the present time the rate of recession at the Gay Head Cliffs is on the average not more than one foot per annum. It is probably at the present time less rapid than in the past, for the reason that ever since the erosion began it has been operating on the face which has been constantly increasing in height and width and has thus required year by year more time for the removal of the material. I am inclined to believe that the erosion on the average must have amounted to at least two feet per annum.

It is not quite safe to consider these various evidences of erosion as indicating the long-continued wearing of the lands in this district at anything like the rate at which it is now going on. The present activity of the destructive agents is principally due to the energy of the tidal currents, which bear away the sediments. If these sediments are not borne away they effectually prevent the waves from doing their work by protecting the cliffs from the assaults of the sea, as is now the case along the Squipnocket shore. The course of these tidal currents alters with every considerable change of the geography of the coast. It is likely that down to a very recent time a part of the sea south of Nantucket, known as Nantucket Shoals, was occupied by many islands. While these islands existed it is probable that the currents about Martha's Vineyard were far less strong than they are at present. It is also probable that Muskeget channel is of recent origin; before it existed the tidal currents about the east end of the island must have had a very different regimen from that which they have under the existing conditions. In other words, in a region where recent changes of the shore line have taken place it is not safe to assume that the existing rates of erosion have continued for a great period of time.

POSTGLACIAL, FOSSILIFEROUS DEPOSITS OF MARTHA'S VINEYARD.

Dr. F. J. H. Merrill informs me that in 1884 he found in the upper portion of the cliff, nearly in front of the light-house at Gay Head, at the depth of about six feet below the surface, a small deposit of postglacial fossils having the general character of the beds exhibited at Sankoty Head, on Nantucket. On revisiting this locality with Dr. Merrill, in June, 1887, no trace of this stratum could be found. Dr. Merrill's ample experience in the study of deposits of this general nature in the region about New York leads me unquestionably to trust the accuracy of his observations. I am the more disposed to credit them for the reason that in 1860 I found in the immediate neighborhood of the place noted by Dr. Merrill a similar bed of shells which I then assumed to be of Post-Tertiary age. Although my notes on this observation have been lost, my memory of the fact is sufficiently clear to have a value in substantiating Dr. Merrill's observations.

The importance of these observations with reference to our general hypothesis as to the interglacial history of this island is manifest. Notwithstanding the small area occupied by this deposit it seems sufficient to make it clear that after the first advance of the ice of the last glacial period the surface of this region was lowered to the depth of not less than one hundred and twenty feet below its present level. Following the formation of this bed of shells, which took place during the period of subsidence, the ice again advanced, and on its subsequent retreat deposited a thin sheet of ground moraine above the level of stratified material. Thus the succession of events appears to have been the same as that indicated at Sankoty Head.[1]

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[1] See Geology of the Island of Nantucket, Bull. U.S. Geol. Survey No. 52, now in press.

NO MAN'S LAND.

The island of No Man's Land has a length of a mile and a half and a width of one mile; it lies about three miles to the south of Gay Head Peninsula. Although this island has no distinct physical connection with Martha's Vineyard it throws a certain amount of light on the geological structure of the whole district, especially on the history of the deposits formed during the postglacial period. It seems therefore necessary to consider it in this memoir.

The mass of No Man's Land, at least all the beds which are above the level of the sea, consists of glacial drift. The superficial deposits, everywhere bowldery, are disposed in the form of very stony kames, the materials of which are distinctly stratified. Much of this kame material seems to have been shoved about in the forward movement of the ice in front of which it was formed. This kame drift at certain points lies upon a deposit of fine-grained, stratified sand which in turn rests upon the eroded surface of a slightly stratified, blue clay containing a few pebbles of angular form (Fig. 63).

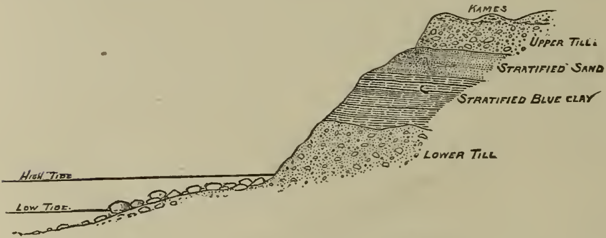

FIG. 63. Diagrammatic section of beds on No Man's Land.

This clay closely resembles that which apparently underlies t whole island of Nantucket and it is in general character like t which is so well exposed in the western portion of the Chilma Weyquosque Cliffs, on the southern side of Martha's Vineyard. On No Man's Land, as at the other points above mentioned, this clay w s evidently much eroded, as if by ice action, though possibly by wat before the sands were deposited, as is shown in the section. On t p of the clay is a deposit of stratified sand of variable thickness; abo e that, a bed of true till capped by kame gravel.

We thus have evidence of at least five distinct conditions in tl se beds: First, the period of the lower or bowldery clays, which have ne general aspect of a very clayey till; secondly, slightly stratified cl ys, which were probably deposited during a period in which the ice ad retreated to some distance from this point; thirdly, the fine, strat d sands, which probably represent the readvance of the ice; fourthly, the upper till, which represents the completion of the readvance; fifthly, the kame gravels of the surface, which were formed in the early stages of the last retreat.

It is evident that the shores of this island, except on the central part of its northern side, are rapidly wearing away. This is well shown by the fact that the cliffs of friable material are almost everywhere steep, and also by the fact that the turf overhangs the edge, often to the extent of a foot or more. It is in this connection a remarkable fact that the island is not prolonged under water by shoals; except on the northern and northeastern faces, we find from thirty to sixty feet of water within a mile of the shore. We cannot well believe that the tidal currents can scour the bottom to this depth, covered as it is with large bowlders.

The central part of the northern shore of the island here, as is shown on the map, consists of a V-shaped sand spit which incloses a small pond. Such spits represent a tolerably balanced condition of the shore currents produced by the beating of the waves against the land. Between No Man's Land and Martha's Vineyard the water is shoal. The accumulation of bowlders at Dove Rock and Old Man's Rocks seems to indicate that we have at those points the remains of morainal accumulations.

ECONOMIC RESOURCES OF MARTHA'S VINEYARD

The economic resources of Martha's Vineyard are limited to its soils and to the clays, sands, and other products already described, which may be had from the deposits of Tertiary age.

The soils of the island are divisible into three groups: those formed of the terrace deposits, those which lie on the moraines that occupy the northern part of the island, and those which lie on the Tertiary beds that occur in the western part of the island, which, though in part morainal in their nature, are somewhat mixed with the subjacent Tertiary deposits.

The soils of the terrace deposits occupy in the main the district extending from the valley of Tisbury Brook eastward to and including Chappaquiddick Island; they extend also as a narrow fringe along the southern shore to the west of Tisbury Brook up to the eastern end of Nashaquitsa Cliffs. But in this limited part of the island the terrace deposits have been enriched by a share of the clay derived from the Tertiary series. A slight enrichment has also taken place from the same source in the region about Edgartown village. Elsewhere these terrace soils are composed in the main of siliceous sand, there being very little clay in their composition. The result is that the rain penetrates quickly through the superficial layer and so washes away a large part of the materials which have been brought into solution by the action of vegetation. The same porosity tends to prevent these soils from retaining sufficient moisture to enable plants to meet the ordinary droughts of the summer season. The result is that these terraces and sandy kames afford soils which are in their natural state rather sterile, except perhaps in the extreme southern part of the island, where, owing to the distance from the old ice front, the sand is of a finer texture and contains a small portion of clay. In time, when the demand for land becomes much greater than it is at present, these soils may have a value sufficient to warrant their improvement by the addition of clay and the marls which abound on the western part of the island, but at present their best use is for timber culture. For this use they are in many respects well fitted. As soon as a forest bed is formed on soils of this nature its spongy quality serves to retain moisture and to prevent the excessive downward penetration of the rainfall and the soluble mineral elements. In plowing, this protecting covering is broken up and destroyed; hence very thin soils frequently do well in timber when they will make no return to tillage.

This generally untillable area of Martha's Vineyard has an extent of about thirty-three thousand acres. At present about twenty-five thousand acres of this area is covered by low, scrubby woods, principally composed of varieties of small oaks; the remainder consists of abandoned fields which are slowly returning to the condition of forest. Frequent fires sweep over the district, destroying the parts of trees which are above ground, but not injuring the roots, from which a tangle of stems quickly springs up. Originally this region was heavily wooded, mainly with coniferous trees, the present prevalence of the deciduous species being due to the peculiar endurance of their roots in the fires, a capacity which does not exist in the conifers.

The greater part of this land is not at present valued at more than $2 per acre and much of it could probably be bought for a less price. It is all near the sea, and therefore its timber product would be readily accessible to the market. The timber trees best suited to this soil have yet to be determined, but it seems to me from an inspection of the existing trees on the island that, in the several parts of this field, suitable localities can be found for larches, catalpas, ailantus, white ash, white oak, hickory, and black locust, all, excepting the white oak, trees of tolerably rapid growth and all of much commercial value. Some of the swampy districts of small total area would probably be found suited to the swamp cedar.

Another much more limited class of lands, now neglected, are the swamps of both salt and fresh water origin which exist on this island. The total area of these inundated lands does not exceed fifteen hundred acres and the separate patches are very small. The area of these swamps is less than the average on equally extensive surfaces of the Atlantic Coast line. Excepting an area of about three hundred acres these swamps were originally of marine origin, though in many cases they have been changed to fresh-water swamps by the recent barring out of the sea from the bays in which they lie. The rapid growth of these barriers of sand, especially along the southern shore, has so far excluded the tide that the marine marshes have ceased to grow with their usual speed; at the same time these ponds are too frequently inundated by the sea to permit the growth of the fresh-water swamp plants.

Along the southern and eastern shores of Martha's Vineyard there are considerable areas of these swamp lands which are tolerably well fitted for improvement. It is doubtful, however, whether any of these semi-marine swamps will prove as suitable for agriculture as the salt-water marshes of the mainland, owing to the variable level and the saltness of the water about them.

The fresh-water swamps of this island are very small in area and inconsiderable in number. They are essentially limited to the western end of the island, i. e., to the region which lies on the surface of the Tertiary deposits. The only considerable areas are those along the borders of Tisbury Brook. The other swamps of this nature lie in the depressions between the rolling hills of drift; a few hundred acres of fertile land may be won from them.

MINERAL RESOURCES OF MARTHA'S VINEYARD.

CLAYS.

The Tertiary beds of this island have a considerable economic interest for the reason that they contain a number of substances which are of use in the arts. First among these are the clays, which, with their connected sands, exist in great variety and in inexhaustible quantities. As is shown on the map accompanying this report (see Plate XX) these beds underlie the whole district from Tisbury Brook westward to the cliffs of Gay Head, except where the area is occupied by the lignite or the sand deposit. Probably more than one-half this area is underlaid by deposits of some economic value. Unfortunately the greater part of this area is covered by a thick covering of drift, which makes access to the clays, in an economic sense, impossible. Still, over an area of at least six square miles, they are sufficiently near the surface to be worked without excessive cost, and at Gay Head they are well exposed in the cliff. Thus, excluding the sands and lignites, we may reasonably reckon that these argillaceous deposits may be worked over an area of at least two thousand acres.

These clays are well adapted to a considerable range of pottery uses. They are now, with difficulty, mined from the Gay Head Cliffs. Ships anchor off that harborless shore at a distance of half a mile from the coast, and the material is then carried in small boats, at great expense of time and labor, and loaded into the vessels.

The fact that for many years this costly process of securing the clays has been continuously carried on is proof that it has been of considerable commercial value. A royalty is paid to the town of Gay Head for the privilege of mining these deposits. At present all the clay exported from this district is taken by Messrs. Fiske & Coleman, a firm of Boston potters. The following statements, which have been kindly made to me by Mr. Fiske, give all that I have been able to ascertain concerning the economic history of these beds:

The use of these clays began about twenty-five years ago, but, owing to the difficulties of shipment and the lack of demand, the industry was unprofitable. The first to be employed were the lignitiferous layers, which were sent to Salem, Mass., for use in the manufacture of alum. The results were satisfactory so far as the quantity and nature of the product were concerned, but the European alum was cheaper than that made from materials transported at such cost as it was necessary to incur in taking the clays of Gay Head to Salem. The use of the pottery clays, which began about twenty years ago, was likewise unsuccessful, for the reason that it was carried on under the same difficulties as to shipment. The first systematic work in the development of these clays has been done by the above-named gentlemen. So far their work, though extended over some years, has been experimental, the largest amount of clay exported in any one year being about six hundred tons in 1885. Their experiments show that the red clays serve very well in making the finer sorts of terracotta ware. Certain of the white clays are fitted for the production of fire-brick, but not those of the best quality. The finer sorts of the white clay appear to be suitable for the commoner uses to which kaolin is put. So far they have only been used for tile work. It is probable, but not certain, that they would answer for making porcelain. A large number of borings have been made by Messrs. Fiske & Coleman in the towns of Chilmark and Tisbury. It appears from these trials that the clays, especially those of a white color, are of rather better quality in that part of the island which lies directly east of Menemsha Pond than in the Gay Head Peninsula. The work of exploiting the clays of Gay Head is rendered difficult by the constant slipping of the cliffs, which, though naturally slow, becomes rapid when any excavations are made at their base. This slipping tends to commingle the several strata, thus making it impossible to keep the product of the requisite purity. It is therefore important to develop the clay beds in the region away from the seashore.

So far only the argillaceous materials of this series of beds have been commercially used. It is likely, however, that there are several other substances contained in these beds which will have a considerable value in the arts. The sands of the Tertiary series are remarkably pure. Some of the beds can probably be used for glass making; other beds appear to be well suited for making certain varieties of fire-brick. A portion of the sands where the quantity of feldspar is considerable may possibly serve as a source of kaolin for use in making porcelain, the coarse-grained silica being removed by washing.

LIGNITES.

The lignites which abound in this series, and which in the aggregate have a thickness of several hundred feet, are very impure, as is the case with all such deposits as are composed of driftwood accumulated at the mouth of a river. It is therefore not probable that they can ever be used for purposes of fuel unless for some manufacturing process carried on upon the ground. Some of these beds, however, contain nodular iron pyrites which in certain parts of particular beds probably amount to as much as 10 per cent. of the weight of the mass. It may be that this pyrite can be extracted by washing at a cost which would make its production profitable. The cost of excavating the soft lignite will be small, at least so long as the work is done in open cuts, or it could be effected by steam shovels.

These lignites and their associated clays contain a large proportion of alum, which could readily be extracted by a leaching process. The quantity of alum in the superficial parts of these deposits appears to be so large as to deserve commercial inquiry. Whether this proportion of alum will be found in the beds where they are under cover and also whether the salt is too much contaminated with iron to be useful in the arts are questions which can only be decided by actual trial.

PHOSPHATES.

From the commercial point of view the most interesting portion of these Tertiary beds is found in certain strata which may be valuable for agricultural fertilizers. There are several layers in the Gay Head section which may be valuable for this purpose. Of these the most important are the several beds indicated in the general section (see Pl. XXVI) which contain bones, principally those of whales. These fragments of bones are generally so admixed with quartz pebbles that I doubt if they are likely to have any economic value.

One of the most promising portions of this section lies at the northern end of that part of the Gay Head escarpment which faces about west. It is about one hundred feet in thickness and consists of dark greenish-gray sands and clay, which in part are somewhat oölitic in structure. These beds contain a considerable quantity of cetacean bones. They also contain a certain amount of phosphatic nodules which vary in size from a tenth of an inch in diameter up to five or six inches. An analysis of these nodules will be found in the subjoined tables of analyses. Both the nodules and the fragments of bone, as remarked by Dr. Hitchcock, have probably been derived from pre-existing strata, the débris of which makes up this part of the section. At some points in this bed the quantity of phosphatic nodules and fossil bones seems to me sufficiently great to make the deposit worth examining with a view of determining if it has commercial value. The analyses of certain of the clay beds, as shown in the tables, appear to indicate that certain of the clays may have a value for fertilizing purposes.

IRON ORES.

The late Professor Hitchcock, in his report on the geology of Massachusetts, has noted the occurrence of iron ores in and upon these Tertiary rocks. These ores appear in the form of bog ores, which have recently been deposited in the existing swamps, and also in the form of thin, irregular beds of limonite in the Tertiary series. After a careful inspection of these deposits I am satisfied that they are not likely to prove of any commercial value.

On the sea beaches of this island we find the sand more or less mingled with magnetic-iron oxide. Although a test by the magnet reveals the presence of this material in all the beach sands, it is only beneath the cliffs which are rapidly wearing away that it exists in considerable quantity. On the beach below Nashaquitsa Cliffs and on that which extends from the village of Vineyard Haven to the West Chop light-house these magnetic sands are more abundant than elsewhere. On either of these beaches it would be easy to gather many thousand tons of sand which would be found to contain from 10 to 20 per cent. of magnetite. It seems to me probable that these deposits may prove of economic importance. As appears from the analysis (see table of analyses, next page) the magnet effects a perfect separation of the iron from the sand in which it is contained. This magnetite contains a certain portion of titanium and is therefore to be classed as an ilmenite.

Examination has shown that the magnetite exists as disseminated grains in the glacial deposits of this island and that, the lighter sands being washed away, it remains in a concentrated form at the foot of the ocean cliffs.

MINERAL WATERS.

The only remaining mineral resource of the island, one which has remained as unnoticed as the fertilizing deposits before referred to, is the mineral waters derived from the Tertiary beds. So far I have been able to observe these waters only on the escarpment of Gay Head, where they appear as small and uncared-for springs.

Some of these waters contain considerable quantities of iron; others are charged with alum; others are weakly charged with sulphureted hydrogen.

As this is the only part of our northern seacoast where, so far as my information extends, mineral waters are found in any variety, they may have some value commercially because of their therapeutic qualities. It is not probable that the sulphurous waters can be found in sufficient quantities or sufficiently charged with the gas to make them useful, but the chalybeate waters and those containing alum can readily be secured by ordinary wells in many parts of the area which is underlaid by the Tertiary beds. At Gay Head the quantity of these waters which could readily be gathered by a little care of the existing springs amounts to several thousand gallons per diem. Ordinary wells sunk in the earth at the base of the cliffs would supply any amount likely to be required for medicinal purposes or for baths.

For the proper development of the resources of the Tertiary district of Gay Head it will be necessary to have a harbor at this end of the island. Apparently the most satisfactory way of securing such a port, and probably the cheapest as well, would be by means of a dredged channel giving access to Menemsha Pond. This channel would require two short jetties for its protection at its seaward end. Access to such a harbor would possibly be of value to the coasting vessels as well as to the mining interests of the island. The local interests would be well served by a smaller one formed by a breakwater projecting from the shore at Menemsha Bight.

ANALYSES.

Analyses of clays and sands from various parts of Vineyard and Weyquosque series.

Mineral.	Loss on ignition.	SiO_2	Al_2O_3 + Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	P_2O_5	Total.	Remarks.
Red clay, southernmost end of Gay Head.	9.83	57.50	31.21	0.19	0.20	.....	.....	.....	.....	99.33	Alkalis, .40.
White, sandy clay, south end of Gay Head.	10.79	56.19	30.65	None	Trace	.....	.....	2.45	None	100.08	
Fine, white clay, south end of Gay Head.	6.36	73.46	19 06	None	Trace	0.70	0.73	None	None	100.31	Frits slightly on ignition.
Average sample white clay, north end of Gay Head.	11.47	49.19	39.77	None	Trace	.....	.....	.....	None	100.43	
Average sample white clay, east end of Chilmark Cliffs.	3.47	32.95	13.45	None	Trace	.....	.....	.....	None	99.87	
Average sample pyrite clay, west end of Chilmark Cliffs.	.....	47.76	30.93	None	0.38	.....	1.17	.....	Trace	.....	FeS_2, 7.27; SO_3, 0.43.
Clay, east end cf Weyquosque Cliffs.	3.39	70.81	20.67	Trace	1.99	1.23	1.67	.....	None	99.76	
Clay, middle of Weyquosque Cliffs.	5.76	61.76	25.35	0.51	1.95	1.83	3.01	.....	Trace	100.17	
White sand, Gay Head ..	.....	78.69	15.64	Trace	.....	0.19	1.09	.....	.....	.....	MgO and H_2O undetermined.
Pyritiferous clay, central part of Gay Head section.	5.69	72.74	21.46	None	Trace	.....	.....	.....	None	99.89	
Brown clay, south of Gay Head light-house.	7.57	56.62	31.24	Trace	1.97	0.40	2.76	.....	None	100.56	

Analyses of material resembling greensand from northern end of Gay Head section.

[The two samples are from the same locality and both are intended for averages of the beds.]

	No. 1.	No. 2.
Phosphoric acid, P_2O_5	0.22	0.48
Carbonic acid, CO_2	0.14	0.16
Lime, CaO	0.65	1.09
Soda, Na_2O	0.33	0.38
Potash, K_2O	4.16	3.87

Analyses of average samples of fossil bones (cetacean) and phosphatic nodules from the above-mentioned greensand.

	Fossil bones.	Nodules.
Phosphoric acid, P_2O_5	27.80	23.88
Carbonic acid, CO_2	3.28	2.60
Lime, CaO	27.21	25.73
Potash, K_2O	0.97	0.15
Soda, Na_2O	0.56	
Silica, SiO_2	....	17.82

Analysis of magnetite separated by the magnet from sand of Chilmark beach (material dried at 104°).

	Per cent.
Iron (Fe)	69.87
Titanium (TiO_2)	3.64

All the above-named analyses were made in the laboratory of the U. S. Geological Survey and reported to me by F. W. Clarke, chief chemist. Though incomplete, they are in the form requested. It did not seem to me necessary for the end in view to have ultimate analyses of any of these materials.

APPENDIX.

Since the foregoing paper was written I have received the following report of the results of Professor Whiting's successive surveys in Martha's Vineyard. As his statements are of much geological interest it seems well to give them in the form of an appendix.

U. S. COAST AND GEODETIC SURVEY OFFICE,
Washington, September 15, 1886.

MY DEAR SIR: By permission of the Superintendent I am glad to give such statements of the results of my late resurveys on Martha's Vineyard as I am able to make at this time. I hope they may contain some of the facts and data you desire in regard to the changes which have occurred.

My first mapping of the topography of the island was in the latter part of the summer of 1845 and the first part of 1846. Later, in 1846, I made the survey of Nantucket. In 1856, ten years subsequent, I made a resurvey of the then new opening from the south into Cotamy Bay, and in 1871 a second resurvey, showing the closing, much to the eastward of its original position, of the inlet of 1856. My present or last resurvey shows the second new opening into Cotamy Bay of January, 1886, nearly in the site of the artificial cut attempted by General G. K. Warren in 1871.

The changes which have occurred during forty years along the south shore of the island give an interesting illustration of the movement which you yourself have termed a "rolling beach" and of the power of the sea-dash upon a sandy shore to drive this material before it. The geographical position of this beach, so far beyond the trend of the main land and its straight alignment, presents an unobstructed front to the wave action, and, although in occasional storms the breakers come upon the shore in oblique directions, the prevailing action of the sea-dash is normal to it. Even in gales from the southeast and southwest, after the force of the wind has subsided the breakers roll in more directly from the south.

Where the beaches have been low, particularly in front of the several ponds, the overshot (so to speak) of the sands has made a greater encroachment upon the waters of the ponds and the marshes inside of the beach than the sea-dash has effected in the outer shore line opposite. The general recedence of the shore along the central part of the main island I should estimate at about one hundred and seventy-five to two hundred feet. At the crest of the summit of the bluff at Nashaquitsa Cliff, which is about one hundred and fifty feet high, the maximum waste is about two hundred and twenty feet. Opposite Chilmark Pond the maximum waste is about one hundred and eighty feet, and the overshot of the sands into the former waters of the pond, near the present opening, is about five hundred and twenty-five feet. At Great Tisbury Pond the outside wastes east and west of the present opening are, respectively, about one hundred and eighty and one hundred and forty feet, while the corresponding encroachments inside are, respectively, about six hundred and eighty and four hundred and eighty feet. Quite a peculiar coincidence occurs in the present position of the opening[1] into Great Tisbury Pond with that of

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[1] The present inlet is a little farther inland, corresponding to the recedence of the shore.

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1846, which is also about the same width, while in the intervening time, about twenty-five years, an inlet has been opened and closed about three-fourths of a mile farther eastward. Most of the inlets of the south ponds, as you are probably aware, are opened artificially for the purpose of improving the fisheries and to prevent the overflow of the marshes by the fresh waters of the ponds. When once opened the width and depth of the inlets are established and maintained by the equilibrium of forces of tidal scour and sea-dash. They sometimes remain open for several months and again are closed by the first heavy storm. The most considerable movement of the entire beach occurs along the front of Great Herring Pond, in Edgartown, where the whole mass of the beach has been driven in upon the former waters of the pond a distance about equal to twice the width of the beach, the general recedence being about four hundred and eighty feet.

The effect of the overshot of sands referred to has changed, to some extent. the pond features of the shore. The group of smaller ponds between Mattakeset Bay and Great Herring Pond has been entirely obliterated and the southwesterly cove of Job's Neck Pond converted into a separate pond. These changes confirm, in a degree, the tradition of the continuous pond or sound along the south face of the island and that the present series of ponds are but the inner coves or arms of this larger sheet of water.

The new opening through Cotamy beach (so called) occurred on the night of January 9–10, 1886. After a gale from the ENE. the wind shifted to WSW., still blowing a gale. The "west beach," as the portion west of the new inlet is now called, was quite low before this gale occurred, and after the shift of wind the whole beach, in 'longshore phrase, was a "breaker." A very high tide, one of the highest in this locality since the Minot gale, accompanied this storm. The general opinion is that at the time of the high tide of the bay the opening was first made by the outgoing or southerly current. As soon as the beach could be visited for observation the opening was already, by estimate, about one hundred yards in width.

Contrary to the usual action of the inlets or openings on the south side of Martha's Vineyard, and particularly those through Cotamy beach, the resultants of the moving sands which form the "chops" of the new inlet have been to the west. This, however, will probably prove to be but a temporary movement and eventually the opening, as all previous ones have done, will work eastward. The present condition of the beach, however, may retard this action from the fact of the comparatively small amount of material in that part of it west of the new opening, where the beach is unusually low. One of the forces which cause an easterly movement of the opening is the encroachment of the west chop upon the channel, and, by contracting it, causing a corresponding waste or cutting away of the East Chop. Formerly the higher sand hills of the beach supplied material for this encroachment. The high sand bank which existed near the outer shore line in 1871 was probably one of the causes, if not the main one, which filled up the cut made by General Warren.

A feature of interest, physically, and as a means of shelter for this exposed fishing ground, is the increase in size and elevation above high water of Skiff's Island. For the last twenty years this has been little more than a shoal, dry at high tide. By my survey of August 15 last this island now lies about southeast from the southeast point of Chappaquiddick (Wasque Point) and distant from shore to shore about one and one-eighth miles. At the date named it was about twelve hundred feet long, north and south, with a greatest width of about two hundred and ninety feet, and contained about four and a half acres. Probably for the first time in the last fifty years beach weeds and grasses have taken root and are growing upon it. It is, of course, a matter of speculation, without hydrographic data, as to whether or not the increase of Skiff's Island is due to the influence of the currents and counter-currents caused by the new opening. As the island is more directly under the influence of the greater volumes of water passing through Muskeget channel, the new opening would seem but a small factor in the problem.

There is quite a remarkable coincidence in the geographical position of the present opening into Cotamy Bay with that of 1856, the present opening being about one-half its width east of the site of the former one. The width and depth of the respective inlets are quite similar. The width from chop to chop of the present inlet on July 1 was about twelve hundred feet.

The various surveys of the beach between the new inlet and Wasque Point show some peculiar local changes. The original upland of the south face of Chappaquiddick has been considerably abraded. The maximum waste at two points is, respectively, about five hundred and eighty and five hundred and fifty feet. On the other hand, the long tongue of beach that formed the outside of the channel that ran along this face of the island from the southeast corner of Cotamy Bay to Wasque Point, and closed there in 1871, still remains in part as an outside beach formation beyond the fast land of the island. The extension of this beach (at the point first named, where the waste of the original fast land is 580 feet) is about six hundred and twenty feet, so that there is now a beach formation about twelve hundred feet beyond the outside line of fast land. At the second point named, where the waste of original fast land is 550 feet, the present beach formation about coincides with the original shore line, or is only about twenty feet beyond it. Again, about a quarter of a mile eastward the present outline of the beach is about six hundred feet beyond the original shore line of 1846. At the apex of Wasque Point the present shore line of the beach is about two hundred and seventy-five feet beyond the former shore line. This advancement of the beach along the east face of Chappaquiddick gradually decreases until, at about half a mile north of Wasque Point, the present and former (1846) shore lines nearly coincide. This coincidence of shore line continues along the whole extent of the east side of the island, showing that there has not been much action of abrasion along the pathway of Muskeget Channel. At Cape Poge, however, the waste has been considerable, owing to the salient position of the apex of the cape. The light material of the bluff, of about twenty feet in height, has given way before both northeast and southeast storms. The waste at the point of the cape is about four hundred and twenty feet. The crest of the summit of the bluff opposite the light-house is now within about forty-five feet of its foundation and is rapidly wearing away.

Along the north side of Chappaquiddick, from Cape Poge to the point opposite the village of Edgartown, the changes in the shore line have not been so great nor has the exposure been of the same character as that on the outer faces of the island.

Very truly yours,

HENRY L WHITING.

Prof. N. S. SHALER,
Harvard College, Cambridge, Mass.

THE GEOLOGY OF CAPE ANN, MASSACHUSETTS,

BY

NATHANIEL SOUTHGATE SHALER.

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LETTER OF TRANSMITTAL.

United States Geological Survey,
Atlantic Coast Division,
Cambridge, Mass., June 20, 1888.

Sir: I herewith transmit to you the manuscript of a report on the surface and under Geology of the Island of Cape Ann and the neighboring parts of the Massachusetts shore. Although I have long had this work in contemplation and accomplished a small part of the task more than twenty years ago, by far the larger part of the field observations embodied in this memoir have been made by my assistant, Mr. Ralph S. Tarr. All the detailed observations on the dikes and joint planes and on the petrography of the district are his. In these parts of the work I have supplied only the general project and certain details concerning the method of presentation. In the petrographic work we have had the assistance of Dr. J. E. Wolff, assistant geologist of the Survey.

I am indebted to Messrs. George Bridge Leighton and John L. Gardner, jr., for their services in obtaining photographs from which all the illustrations of this report have been prepared.

Very respectfully, your obedient servant,

N. S. Shaler,
Geologist in Charge.

Hon. J. W. Powell,
Director U. S. Geological Survey, Washington, D. C.

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THE GEOLOGY OF CAPE ANN, MASSACHUSETTS.

By N. S. Shaler.

NATURE AND OBJECTS OF THIS REPORT.

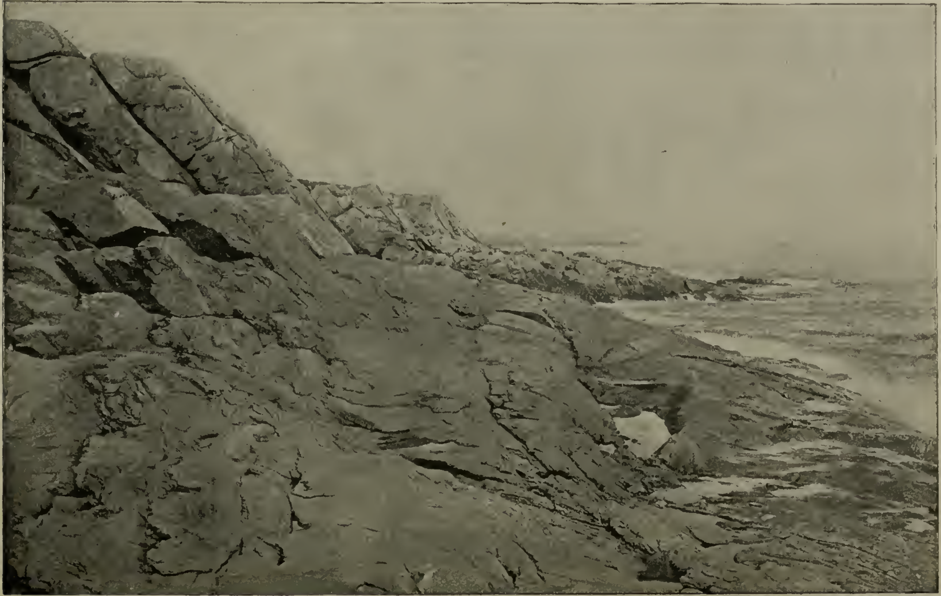
The island of Cape Ann and the neighboring portion of the mainland of Massachusetts form a remarkable salient at the northern extremity of Massachusetts Bay. The topographic individuality of this area and its general relations to the shore line of New England make it an attractive field for inquiry. Although it is proposed in the end to assemble in a general report the information gained in the study of the Atlantic coast line, it seems desirable from time to time to set forth the more important of these results in the form of detached memoirs. It will be a number of years before it will be possible to prepare a final report, and in the mean time by separate publications, the more important results obtained during the progress of the inquiry can be placed in the hands of other students of this interesting geological field.

I propose to set forth in the following pages what has been ascertained concerning the following points: First, the general structure of the district in question, and next, the superficial geology of this field under the following heads, viz: the distribution of the glacial drift, the amount of erosion during the last ice period, and the action of the sea upon the shores; afterwards I shall take up the structure and nature of the bed rocks, the variation in the character of the hornblendic granitites which compose the region, the various dike stones which intersect it, the character, origin and effect of the joint planes and the quarry rifts of the rocks, and, lastly, the relations of the region to the anticlinal axis of which it forms a part.

The field included in this inquiry at first sight appears to present little of geological interest; it has received hardly any attention from the geologists who have worked in eastern Massachusetts. This neglect is due to the fact that the geologic structure of the region is relatively simple. As will be seen from the geological map accompanying this report, the bed rocks are composed altogether of granitites and associated intrusions of an igneous nature. The absence of distinctly stratified deposits gives a uniform aspect to its structure and appears at first sight to afford little promise of important results to geological inquiry. Despite the disadvantage arising from the lack of variety, this region affords certain peculiar advantages to the student for the prosecution of various inquiries. The general deforested condition of the island of Cape Ann, a feature which is shared in part by the mainland division of the area included in this report, enables the observer to note certain peculiarities in the distribution of the drift which are often obscured by forests in other parts of this region. The extensive shore line and the thoroughness with which the rocks near it have been stripped of their original covering by the action of the sea make it possible to observe the details of structure of the rocks along a section which has a length of more than thirty miles. (See Pls. XXXII–XXXV.) As will be seen hereafter in the body of this report, we are able from a study of this section to determine in a satisfactory manner many points concerning the structure of the rocks. The extensive quarries which exist also favor the prosecution of several inquiries.

These favoring features made it seem desirable to undertake on this ground a careful study as to the distribution of dikes in a mass of crystalline rocks, which, as we shall see hereafter, originally constituted the foundations of a great anticline. The field also seemed advantageous for a careful study of joint phenomena in their relation to the dikes, and to the strains which we may assume to have been developed in the formation of the anticlinal ridge. In this connection it also seemed well to undertake some inquiry into the nature of the rift or natural splitting planes which are availed of by the quarrymen in the separation of blocks of the granite from their bed. I am not aware that any of these inquiries have ever been prosecuted in the manner in which they are considered in this report. Lastly, the peculiar composition of this shore in relation to the sea makes it possible to study the effect of ocean waves of great magnitude on rocks which, though generally hard, vary much in the resistance which they offer to the impact of the waves. No other point on our coast line affords such opportunities for this inquiry as Cape Ann. The considerable extent to which this promontory projects into the open sea and the absence of reefs or other barriers between it and the wide ocean, together with the deep water which extends seaward from the shore, expose it to more powerful surges than assail most other parts of our rock-bound coast. As will be seen in the section of this report which deals with the problem of marine action since the close of the glacial period, we learn much from studying here the action of the sea.

The promontory of Cape Ann projects about twelve miles from the general line of the shore. It is composed of two sections, an outer part, made up of the main island which receives the name of the cape, and a few small islets all having a core of bed rock more or less enveloped with detrital materials, and an inner section which, though much cut up by deep indentations of the sea, is not completely sepa-



CLIFFS NEAR LOBLOLLY COVE, SHOWING POST-GLACIAL MARINE EROSION, FORMING DISTINCT BENCH ALONG THE SHORE.

rated from the mainland. The outer portion of the promontory, to which we give the name of the Island of Cape Ann, was at the close of the glacial period and for some time thereafter completely separated from the mainland by the tolerably deep inlet which bears the name of Squam River. The considerable amounts of detrital matter borne in by the sea which have accumulated in the Gloucester harbor have in recent times closed the southern extremity of this fiord by a beach wall. Behind this wall the usual growth of marine marshes still further effected the closure, so that when the country was settled by Europeans there was an isthmus of marsh and beach having a width of about one-third of a mile which separated the waters of Gloucester harbor from those of Squam River. This barrier has been artificially cut through so as to permit the passage of boats, and thus the original insulated character of the cape has been restored.

The fact has been stated that the whole of this salient is much exposed to the action of the ocean surges. An inspection of the soundings given on Coast Survey Chart No. 109 shows that they rapidly and somewhat uniformly descend from the shore line towards deep water. The ten-fathom line is generally found at a distance not exceeding a mile from the shore, and at several places, particularly near Eastern Point and near the northern promontories of the island, it comes to within less than half a mile of the shore. The contouring line drawn on the soundings of twenty fathoms is at no point more than two and a half miles from the shore of the main island and generally is not much more than one and a half miles from its margin. Beyond the twenty-fathom line the bottom descends steadily to the depth of from twenty-five to fifty fathoms, these depths being generally attained at distances of not more than four miles from the coast. A comparison of the position of our shore with reference to deep water will make it plain that these features of the bottom favor the action of ocean waves on this part of the coast, and therefore fit the shore to be the seat of special inquiry on this point.

GENERAL GEOGRAPHIC AND GEOLOGIC RELATIONS OF THE CAPE ANN DISTRICT.

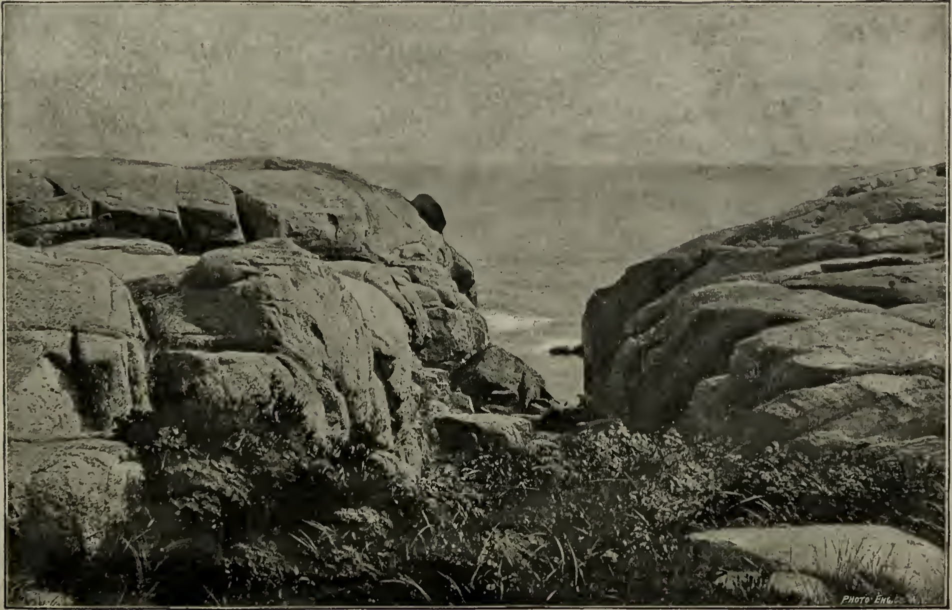
The island of Cape Ann is composed altogether of three classes of rocks—an original field of the nature formerly known as syenites, rocks now designated by petrographers under the name of hornblendic granitites, which occasionally approach a true granitic character. These granitites, as we shall afterwards show, probably represent a succession of dislocatory movements partially due to true injections and in part to faulting, the variations in the character of the crystalline matter being due in the main to these displacements.

Through these granitic bed rocks, which compose about nine-tenths of the foundations of the district, extend very numerous dikes. As will be seen on the map, considerable portions of the shore line are so far penetrated by these intrusions that more than one-tenth of the surface is occupied by them. Unfortunately for the completion of the observations, the internal area of Cape Ann as well as of the neighboring mainland is pretty deeply and evenly covered by glacial drift, more than three-fourths of those areas being hidden from view. All the evidence, however, goes to show that the proportion of dike stones to the common granites is quite as extensive in the interior and drift-covered areas as it is along the extended shore line.

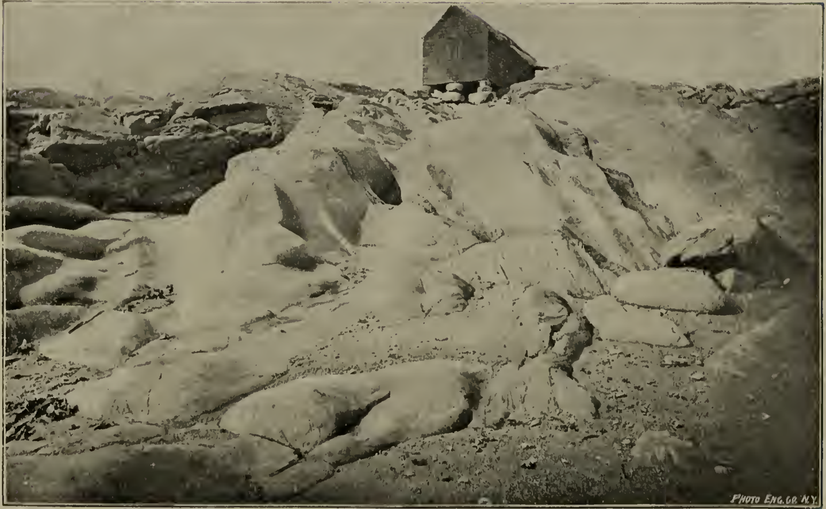
On top of the bed rocks we have, as before remarked, an extended sheet of drift deposits distributed with greater uniformity than along any other portion of our shore known to me. As will be seen hereafter when we come to set forth the results of special study on this drift deposit, it consists mainly of frontal moraine or material which has been shoved forward at the front of the ice sheet.

In none of its geological features, neither in its bed rocks nor in the injected materials nor in the drift, does the region of Cape Ann have an individual character. The granitites which appear and which constitute the greater part of the region are essentially like those occurring all about the borders of Massachusetts Bay. With slight exceptions the dike stones are paralleled by others found in various parts of eastern Massachusetts. The morainal accumulations are but fragments of a large field in which these deposits occur. The peculiar advantage of this district, that which has led me to make it the subject of a memoir, is found in the fact that several geologic features exhibited there are better placed for inquiry than elsewhere. It will be evident from an inspection of the maps that the Cape Ann promontory is formed by the northeastern projection of a ridge of crystalline rocks, generally syenitic, extending from near Dedham, Mass., in a northeasterly direction, until cut off by the sea. To the northwest and to the southeast of this extended axis we have rocks of a less crystalline nature verging upward into distinctly sedimentary deposits. On the south side of Boston Bay, extending from Nantasket in a southwesterly direction, we have a similar axis; the two are obscurely united at their southwestern extremity in the highlands and peaks of the Blue Hills, which attain a considerable altitude.

The general structure of these ridges makes it clear that they are in their nature anticlines, and that the Blue Hills district is situated at the southeastern extremity of the trough which is inclosed between them, thus forming what we may term the node of the anticline. Between these two anticlines, within which lies Boston Bay, we have a much disturbed syncline, the only portion of which open to investigation lies in and about the city of Boston. The greater



ERODED DIKE CHASM NEAR WHALE COVE, 20 FEET ABOVE PRESENT SEA-LEVEL.



VIEW NEAR CAPE HEDGE, MASSACHUSETTS, SHOWING SCOURING ACTION OF SEA ON LITTLE-JOINTED ROCK OF VARYING HARDNESS.

portion of this syncline has been entirely cut away by erosive action, by the work of rivers, by the action of the sea, and in larger measure by the erosive power of glacial ice. So profound has been this erosion, that it has not only destroyed the greater part of the sedimentary deposits down to the water-level, but it has also removed a considerable portion of the plutonic rocks which were thrust up beneath the old anticlines, at the same time stripping off all the newer-bedded rocks which originally lay upon their surface.

It is also evident that profound faulting attended the formation of this syncline, accompanied by a considerable development of minor folds within the field occupied by the syncline itself. Through these faults extensive extrusions of igneous rock took place, in part in the form of dikes and in part in the form of more superficial flows, the remains of which are still found in a profoundly eroded condition in the porphyries and felsites of Lynn and in the similar rocks and accompanying ash-beds of Cohasset. From what is left of the old syncline we may fairly arrive at the conclusion that only the southeastern extremity of this trough has been preserved to the present day. By far the greater part of its area has been deeply eroded and is hidden beneath the surface of the sea, in part covered over by recent accumulations of sediment. We shall consider the history of this erosion when we come to treat of the recent abrasion which has taken place on the surface of Cape Ann.

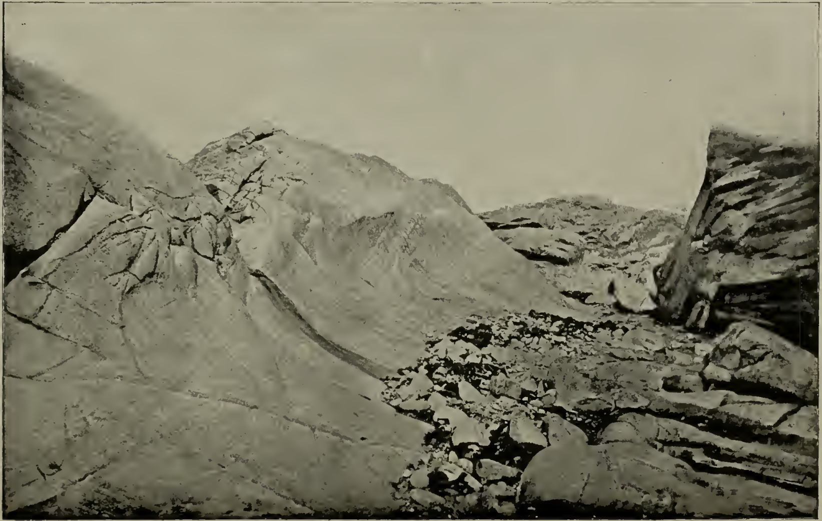
GENERAL FORM OF CAPE ANN ANTICLINE.

Turning now to the general form of the Cape Ann anticline, as we shall hereafter term it, we find that it consists of a somewhat irregular ridge having an average width of about ten miles. On the north this ridge is bordered by lowland worn in the softer rocks which lie upon its north side, and occupied in the main by the drainage of the Charles, the Mystic, the Saugus, and the Ipswich Rivers. The delimitation of the ridge on the north is by no means distinct; it is, however, sufficiently clear to give a certain accent to it on that side. On the south side it is bordered by the waters of Boston Bay.

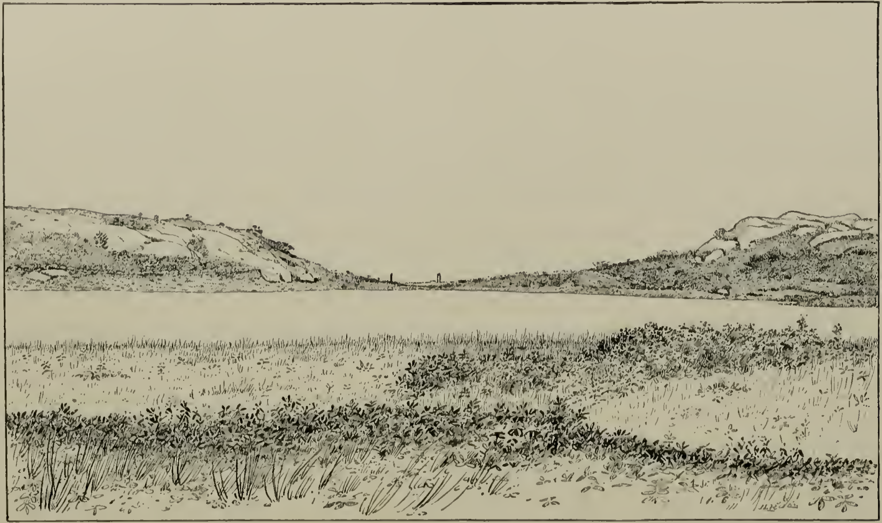
The surface of this anticline, though originally united, is now much divided by a number of tolerably deep valleys, some of which attain to the level of the sea. The southernmost of these, that of Charles River, attains very nearly to the sea level, the highest point of the ridge where it is crossed by the stream being not more than fifty feet above tide mark. The Mystic also forms a deep excavation through the anticline; the Saugus River, though its headwaters do not extend beyond the limits of the ridge, deeply divides it. From Manchester to Essex another depression appears in the axis which attains almost to the level of high tide, and the fiord which separates Cape Ann from the mainland extends, save for the postglacial débris which has accumulated in it, to a considerable depth below the water line. These several troughs owe their existence to pre-glacial streams and in larger share to the work of the ice during the last glacial periods. Besides these conspicuous meridional valleys we find many others having the same general trend and probably to be explained in the same manner, through the action of glacial ice operating on rocks which were mechanically weak.

Besides the above-mentioned valleys this region exhibits another series of depressions, less conspicuous because they are not to the same extent occupied by water, but on the whole equally noteworthy. These valleys extend in the direction of the anticline itself, having a general trend of about N. 10° to 20° E., S. 10° to 20° W. (See Pls. XXXVI, XXXVII.) Although tolerably evident in every part of this ridge, these valleys are most conspicuous in the region in and about Cape Ann. On this island they give more expression to the surface than any other elements of its topography. With the map of the island before him the reader will perceive that the Cape is in good part divided into two regions by the deep indentation of Gloucester harbor and a corresponding indent known as Sandy Bay. Between these two depressions, each of which has a length of several miles, the surface of the Cape is, save for the encumbering envelope of drift, much lower than along the other part of its area. If it were depressed fifty feet below its present level, although but a small part of its surface would be submerged, a nearly complete channel would be formed extending from Rockport to Gloucester, and Eastern Point would be cut off from the main island. Besides this most considerable northeast and southwest valley, there are several others approximately parallel to it on different parts of the island and on the neighboring mainland. One of these extends from the indentation just west of Halibut Point, known as Folly Cove, for a distance of more than two miles into the body of the island. It is possibly protracted across the intervening space to Squam River near Riverdale, though in its central portions it is almost completely effaced by the thick deposits of morainal matter.

The last-named group of valleys has an origin which is not as simple as those which extend in a northwest and southeast direction. In part they are due to glacial erosion on portions of the strata which are mechanically weak. As will be seen by the map, certain belts of dikes containing the most numerous and characteristic of these intrusions have the same course as these valleys. It is likely that the resistance of the rocks to glacial erosion was considerably diminished along the lines which they occupy, and that in part the development of valleys is due to this cause; in part also they may be attributed to a totally different origin. The direction of the morainal fronts corresponds approximately to that of these valleys. The morainal matter is arranged in successive ridges roughly par-



VIEW NEAR CAPE HEDGE, SHOWING SCOURING ACTION OF SEA ON LITTLE-JOINTED ROCK OF UNIFORM HARDNESS.



VALLEY BETWEEN BRIAR NECK AND MAIN-LAND, LOOKING NORTHEAST—THATCHER'S ISLAND LIGHT-HOUSES IN DISTANCE—SHOWING ONE OF THE NORTHEAST AND SOUTHWEST VALLEYS OF CAPE ANN.

allel, the intervening valleys having often the same general character as the troughs produced by the erosion of the bed rock.

Besides the northwest and southeast valleys which are evident in the topography of the country, it is clear that there is at least one other beneath the level of the sea lying in the space between the Salvages and the eastern shore of Cape Ann. Yet another more obscurely indicated lies between Straitsmouth Island and Gap Head, being continued southwardly between Thatcher's Island and Milk Island. Judging from the soundings, it appears likely that there are other north and south troughs partially effaced by sediments on the sea floor farther out from the shore. One such appears about three miles east of Straitsmouth Island and yet others farther out to sea. The insufficiency of the soundings, which, though numerous enough to serve the needs of the navigator, do not meet those of the geologist, makes it impossible to determine with accuracy the form of these interesting troughs.

The soundings also indicate, though obscurely, the extension of the Cape Ann ridge for ten miles or more eastward of its present limit. The ridge which appears to represent the submarine continuation of the Cape is much lower and more rounded than the portion of the anticline which lies above the water level, but the distance between the soundings is so great that a basis for precise conclusions can not be secured.

The height of the anticlinal ridge which includes the district of Cape Ann is remarkably uniform. The most elevated part of it does not lie within the field we are considering, but is found at Bear Hill, in the township of Stoneham, where it is about four hundred feet above the level of the sea. Within the limits of Cape Ann the highest point is about two hundred feet above the sea level. The depths of fiord-like indentations which extend in a northwest and southeast direction is not accurately determined, but probably at no point does it exceed one hundred feet below the ocean level. At first I was disposed to consider this uniformity in height as due to the likeness of glacial action on different parts of the surface. Further inquiry has convinced me that it is to be explained by the operation of the sea in the former geologic periods, when it was at a somewhat higher level than at present. All along our coast we have more or less clear indications of a great planing agent, which has cut off the summits of the mountains back a distance of scores of miles from the present shore line, reducing the surface to something like a general level, leaving a few isolated peaks here and there upon the bench. The level of this bench varies on different parts of the shore. In Massachusetts it ranges from the present level up to the height of about four hundred feet. In Virginia this marine bench is more distinct than in New England, for the reason that its aspect has been less affected by glacial action.

Owing to the action of the sea in former times at higher levels, the mountains of the coast belt, though having as much geological relief as those of the interior region, have been deprived of their topographic value and are planed down to the very roots.

NATURE AND DISTRIBUTION OF DRIFT DEPOSITS.

The drift deposits of this region, though in general character much like those found in the neighboring districts, presents some interesting peculiarities. The whole of the central field of the island of Cape Ann and the neighboring portions of the mainland included in this report is covered with a coating of frontal moraine somewhat irregularly distributed but generally attaining a considerable depth. Here, as generally elsewhere, the accumulations consist of three elements: shoved material, or that which has been urged forward in the advance of the ice sheet as the soil is carried onward in front of a scraper. (See Plates XXXVIII, XXXIX, XL, XLI.) Around this shoved matter, or that which owed its transportation to the advancing ice front, we find accumulation of finer material arranged in the form of kames. (See Pl. XLII.) Yet farther from the former face of the ice lie sheets of sand arranged so as to afford a tolerably horizontal surface to which I have given the name of "frontal aprons." On top of the shoved moraine, and for some distance back of its line, we find deposits which have received the name of "ground moraine," composed of materials originally contained in the body of the ice which at the time of its melting dropped upon the surface.[1]

SHOVED MORAINES.

The frontal or shoved moraine material within the limits of the island of Cape Ann is remarkably thick, having on the average a depth exceeding fifty feet, and at some points possibly exceeding one hundred and fifty feet. (See Pl. XLIII.) It is arranged in the form of rudely parallel ridges, which extend from N. 25° to 40° E. and S. 25° to 40° W. These ridges are very broad and the valleys between them by no means distinct. In most cases they appear to be thickest on the summits of the low elevations of granitite, which are separated from each other by the valleys which we have already described. The surface of these morainal ridges is very irregular, being cast in the mammelate form so common in such accumulation. (See Pl. XLI.) The most remarkable feature observable in this morainal matter is the extreme abundance of large erratics which it contains. (See Figs. 44, 45.) These great bowlders are so abundant that over most of the surface occupied by the shoved moraine they make all tillage impossible. Indeed, on a large part of the area it is

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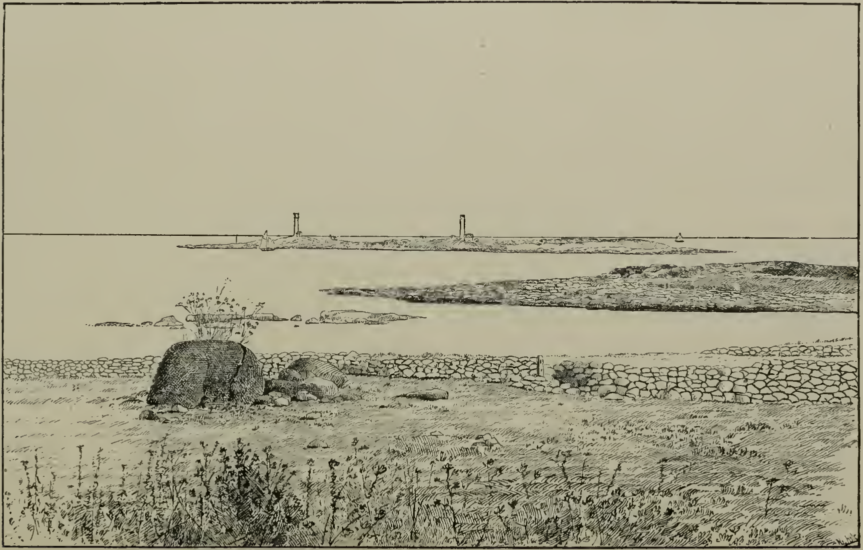
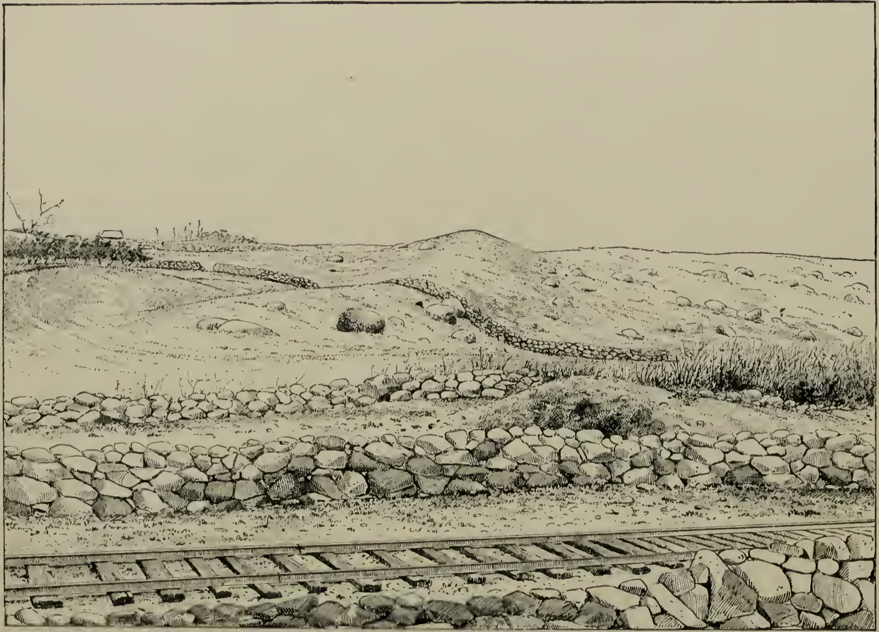
[1] Geology of Martha's Vineyard, N. S. Shaler, Seventh Ann. Rept. U. S. Geol. Survey, 1886-'87, p. 314.



SHORE AT EMERSON'S POINT, WITH THATCHER'S ISLAND IN DISTANCE; LOOKING EAST.



SERPENT KAME DESCENDING NORTH SLOPE OF SOUTHERN FRONTAL MORAINE NEAR ROCKPORT ; LOOKING SOUTH.

difficult to find a place to set the foot between the closely packed erratics. In the most of the morainal matter the proportion of bowlders exceeding one foot in diameter amounts to not less than one-half the total mass. At certain points the percentage of the large erratics is so increased that there is no fine material to fill their interspaces; the result is that the heap remains open, presenting cavities which extend in many cases to the depth of twenty feet or more below the surface, the whole mass appearing in the landscape like the ruins of Cyclopean masonry. (See Pl. XXXIX.)

Wherever the seeds of trees could have found soil enough to afford them root vegetable waste has filled the hollows between the stones and masked the position of many parts of this open-textured moraine. Nevertheless a considerable part of the accumulation, which I have estimated amount to one-fiftieth of the whole, remains completely without vegetable coating except for the lichens which have found place upon the erratics.

FORM OF DRIFT DEPOSITS.

Returning to our consideration of the general form exhibited by these deposits, we note that the southern part of each division of the shoved moraine appears to be steeper and more stony than the northern part. (See Pls. XL, XLI.) This is probably due to the overriding of the moraine in the frequent slight advances of the glacier, and in part to the washing of the sediments from the ice front upon the slope of the moraine as it was abandoned in the process of glacial retreat.

On the northern exposed face of the moraine, the boundary between that accumulation and the surface of the bed rocks is tolerably sharp. The partition between the two areas is generally indicated by a depression, in which lies a series of swamps. This depression is on an average ten to twenty feet in depth and has a width of several hundred feet. North of this trough there are occasional patches of what appears to be shoved moraine material; but the greater portion of the incomplete sheet of detritus apparently has the nature of ground moraine or that which was formed when the melting ice dropped its débris on the surface. At no point have I observed this accumulation having a thickness of more than five or ten feet, and the materials generally occupy less than half of the bed-rock surface.

Although the shoved moraine occupies about three-fourths of the area of the island of Cape Ann, the district contains representatives of the other structures which were formed on the front of the ice. The kame deposits are rare; they are mainly found either upon the southern portion of the island of Cape Ann and the neighboring mainland or on a narrow strip along the northern coast. The origin of these kame deposits can readily be explained, provided we accept the hypothesis concerning their origin which I have elsewhere presented.[1] This hypothesis is, in brief, as follows: From beneath the ice mass there came forth many streams of flowing water, bearing with them great quantities of detrital matter. At the time when these streams flowed the base of the ice was considerably beneath the present level of the sea. On the floor of that sea, immediately in front of the glacier, the whirling currents, originated in the ocean waters by the swift-flowing glacial streams, formed the peculiarly distributed mounds and valleys of stratified débris which we note as kames. These subglacial streams were rare on the part of Cape Ann which is now above the ocean level, for the reason that they were drawn away into the deep valleys which lie east and west of its elevated mass. We know by the facts exhibited elsewhere that subglacial streams, though occasionally appearing along all parts of the ice front, are most likely to find their channels in the depressions of the surface which lie beneath that front. Thus the kame deposits were probably accumulated on territory which now lies beneath the surface of the sea.

In front of the kames normally comes the moranial apron which is so well developed in southern New England. This apron is scantily exhibited for the same reason that led to the paucity of the kame deposits. The materials which compose it were borne to their position by the waters from beneath the ice, and therefore where the kames are poor the apron will be imperfect.

Traces of this frontal apron exist along the southern shore of Cape Ann, especially near Gloucester and in the part of the island which lies east of that town. The traces are so imperfect that they would escape the attention of the geologist who encountered such structures for the first time in this field. The topography of the sea bottom south and east of Cape Ann indicates a general slope reaching outward for some distance from the shore. I have no doubt that the frontal apron determines the uniformity of this slope, as it manifestly does that of the sea bottom south of Nantucket and Martha's Vineyard, where a wonderfully developed frontal apron may be seen to pass below the plane of the sea.

As before remarked, the north shore of the island exhibits some deposits of kame materials and perhaps some faint indications of frontal moraine. It is probable that these structures represent the work of the ice when in its northward retreat it paused for a moment on the portion of the surface which lies below the level of the sea beyond the shores of Cape Ann and there constructed a frontal moraine with its corresponding kame and apron deposits.

As a whole the kame deposits of Cape Ann form an imperfect fringe, extending from Andrews Point westward as far as Annis-

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[1] Geology of Martha's Vineyard, Seventh Ann. Rep. U. S. Geol. Survey.

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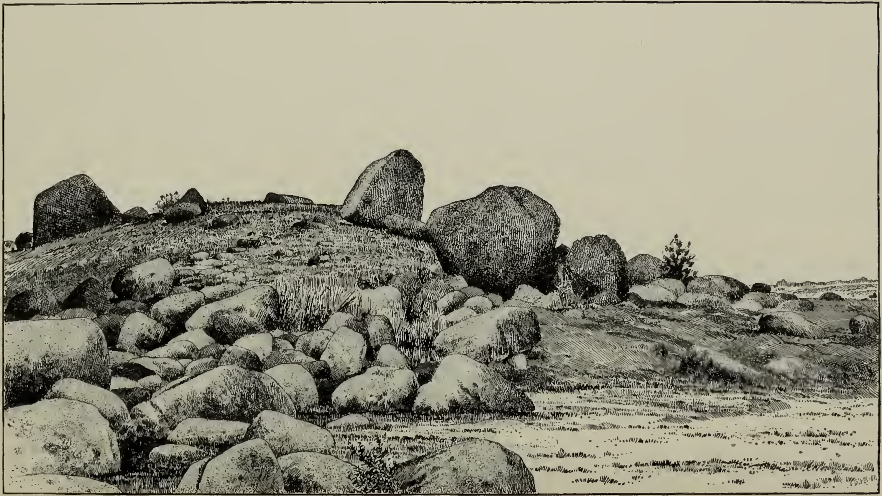
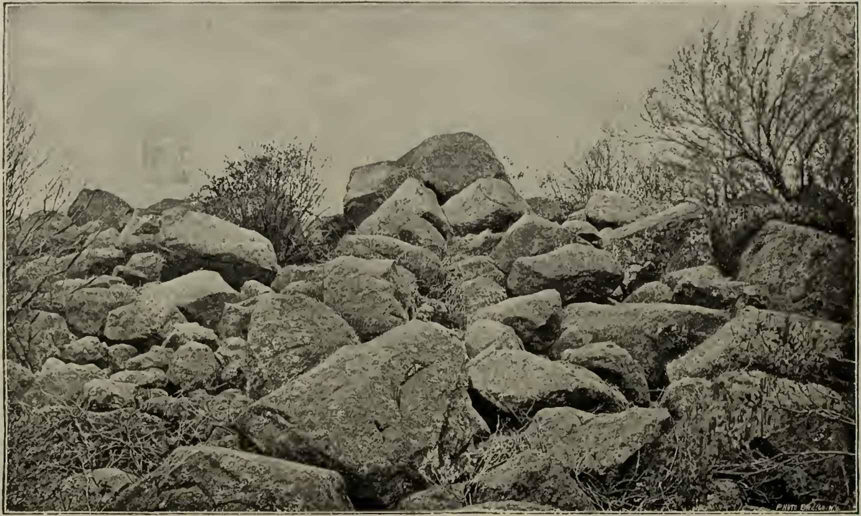


CREST OF NORTHERN FRONTAL MORAINE, LOOKING NORTHWEST; DOGTOWN COMMONS.



VIEW IN THE ROCKY MORAINE ON THE TOP OF GREAT HILL NEAR ROCKPORT MASSACHUSETTS ON WEST SIDE OF GLOUCESTER AND ROCKPORT TURNPIKE; LOOKING WEST.

quam up to the part of the island which lies next to that inlet and thence to Eastern Point. Faint traces of such accumulations lie on Eastern Point and back of Long Beach. Deposits of this nature are, however, distinctly more abundant on the western versant of the island than on the eastern.

Generally the stratified elements of glacial accmulations do not rise more than sixty feet above the sea level. They are hardly traceable in any continuity above the level of 40 feet; but at a few points they extend in an obscure form nearly to the summit of the great moraines. On Dogtown Commons several of these areas of kame deposits were during the period in which this district was inhabited brought into the state of tilled fields, and now appear as samll pasture lands destitute of bowlders. In part this destitution is due to the fact that the occasional bowlders obstructing the plow were removed. These high-lying benches of stratified drift material probably indicate points where small subglacial streams emerged during the process of the retreat of the ice, bringing forth a quantity of detrital matter and depositing it upon the surface of the shoved moraine at a time when the mass lay below the level of the sea. (See Pl. XLV.)

SERPENT KAMES.

Usually included among kames are those peculiar forms of the drift deposits often known in New England as Indian ridges, and to which I have provisionally given the name of "serpent kames," for the reason that they are usually serpentiform in their general shape, singularly recalling the artificial snake mounds of the West. Like the kames, they are composed of more or less stratified materials, and in certain cases they appear in positions which clearly indicate that in some way they are related in origin to the ordinary kettle kames.[1]

There is but one distinct serpent kame known to me in the field that we are considering. It lies on the eastern portion of the island of Cape Ann, near Rockport, on either side of the valley traversed by the railway and about twelve hundred feet southwest of the terminus of that road. Its position is shown on the map. (See Plates XXXVII, XXXVIII).

In many respects this serpent kame is the most interesting in this country. Its total length is not far from one thousand feet, but a portion of it lies on either side of the steep valley where it is found. The general position of the mass is indicated in the accompanying plate.

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[1] It is likely that the Scandinavian "escar" is akin to our serpent kames, but as some deposits which have received that name are probably in their nature drumlins, that is to say, masses of till which have been shaped beneath the ice by the process of its movement, it seems to me best for the present at least to abandon the use of that term.

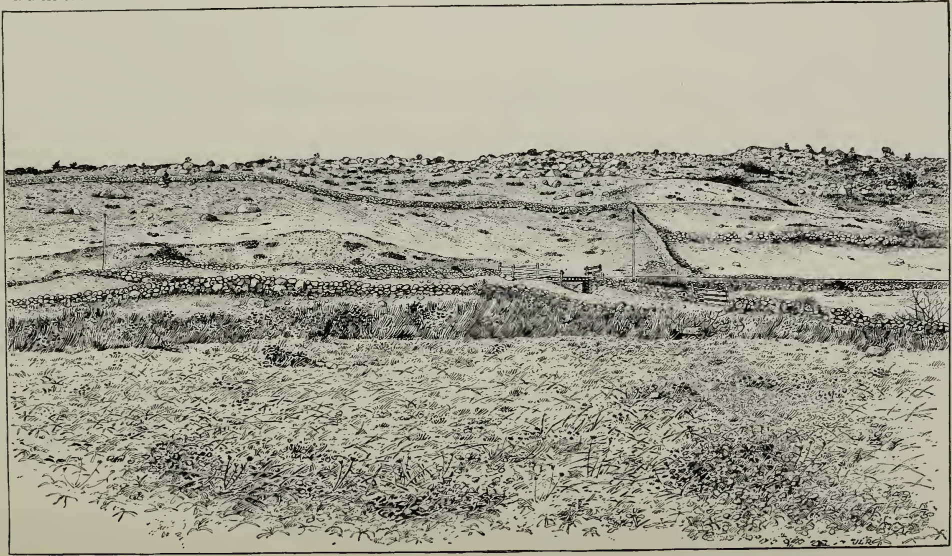
The central portion of the deposit has been in part cut away by the action of the small stream which traverses the valley; in part it probably owes its destruction to the former action of the sea at this level. This is the more likely from the fact that distinct though weakly developed terraces occupy a portion of the valley at a height where the serpent kame is destroyed.

I am disposed to hold, with other glacialists who have considered this problem, that the serpent kames have been formed in the following manner: The outflowing glacial stream excavated channels within the ice which they kept free as long as the currents were strong enough to scour their channels. In the closing stages of the ice sheet, while the front was no longer advancing or perhaps inclined to retreat, these arches were filled in by material borne by the diminished currents. This moraine gives us a better view of the condition of these channels than we obtain elsewhere. We perceive that they are closely molded to the surface, and also that they could be imposed upon considerable thickness of ordinary morainal drift.

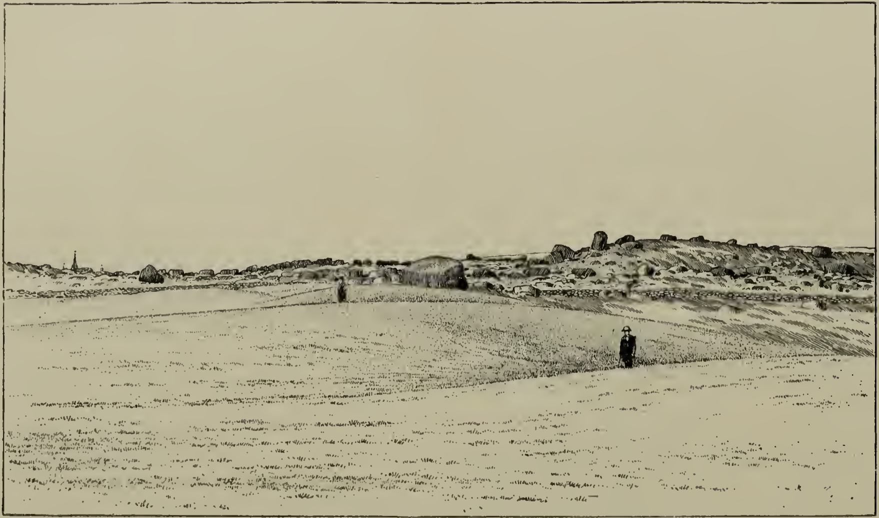
DRUMLINS.

Besides the ordinary frontal deposits above noted, we have in this district a solitary representative of another class of glacial deposits, viz, that of drumlins. This single drumlin lies near Rockport and is known as Pigeon Hill. (See Pl. XLVI.) It is a remarkably good example of its class, and appears in very striking contrast to the surrounding topography. Rising to the height of about two hundred feet above the level of the sea, it has a very symmetrical lenticular form, departing from that outline only on its southern side, where there is a peculiar benching. Unlike the shoved frontal moraine, which lies about it, this ridge is composed, as is usual, entirely of these structures of very compact till in which the proportion of clay is large and the mass extremely compact. Its surface was originally covered by the coating of ordinary ground moraine, containing many bowlders, which have been removed in order to fit it for tillage.

The origin of these peculiar masses of compact till occurring in the form of drumlins is still a matter of debate among geologists. I venture to suggest the hypothesis that they are to be accounted for in the following manner: During the first stage of the Glacial Period the ice sheet had a very much greater extension than during the second portion of the Glacial Period. When at the close of the first stage the ice retreated, it left upon the surface irregular but in places extremely thick deposits of till. During the interval between the first and second stages of the period the southern part of New England remained for a long time free from ice. During this time the till deposit left upon the surface was much eroded, perhaps by the action of the sea, in part doubtless by river action. When the second advance of the ice came to repossess the



SERPENT KAME DESCENDING SOUTH SLOPE OF NORTHERN MORAINE NEAR ROCKPORT; LOOKING NORTH.



ELEVATED KAME PLAIN IN MIDST OF FRONTAL MORAINE, DOGTOWN COMMONS ONE MILE NORTH OF GLOUCESTER; LOOKING SOUTH.

surface, it wore away a large part of the till formed during the first period, leaving the remains of it carved in the characteristic form of our drumlins. It is obvious that these drumlins or lenticular hills have, as the latter name indicates, precisely the form which is given by the action of the ice to any resisting materials of uniform hardness over which it moves. Thus in the Adirondacks, and elsewhere where rocks of uniform hardness exist over considerable fields, we find that glacial action shapes their forms so that at a little distance they are readily mistaken for drumlins.

If this view be correct, Pigeon Hill is a solitary remnant of the original till of the first stage of the Glacial Period, the remainder of that deposit having been worn away by the later action of the ice or entirely covered beneath the thick deposits of shoved moraine.

The outline of the shoved and ground moraine in other parts of the island leads me to suspect that there are several other remnants of this ancient till so far buried beneath the subsequent deposits that their existence can only be conjectured.

A little observation will show the student that nearly the whole of the true frontal moraines in this district have a somewhat drumloid aspect. Each of the moraines is composed of closely crowded hills, the bases of which are conjoined. Looking at these elevations from the east and west, we perceive that they have the general shape of lenticular hills; the curves are not as finished as those of Pigeon Hill or other normal deposits of this nature, but they are of the same general form. In many cases if the encumbering masses of great bowlders were removed the likeness to drumlins would be even clearer than it is at present.

The rounded aspect of these projections of the central moraine is probably to be explained in essentially the same way as that by which we have endeavored to account for the drumlin proper. As is well-known, the front of the glacier is always instable in its position, and a peculiar measure of instability appears to characterize this marginal part of the glaciers belonging to the continental type. We may therefore assume that the cliff-like front of the ice again and again advanced and receded in its position, and at each forward movement there must have been a certain erosion of the deposits which were accumulated during the preceding advances. Although this feature is not very recognizable in the case of this moraine, it is remarkably evident in the Martha's Vineyard moraine, where the overlying of the drift deposits in successive advances is extremely conspicuous.[1]

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[1] Geology of Martha's Vineyard, Seventh Ann. Rept. U. S. Geol. Survey.

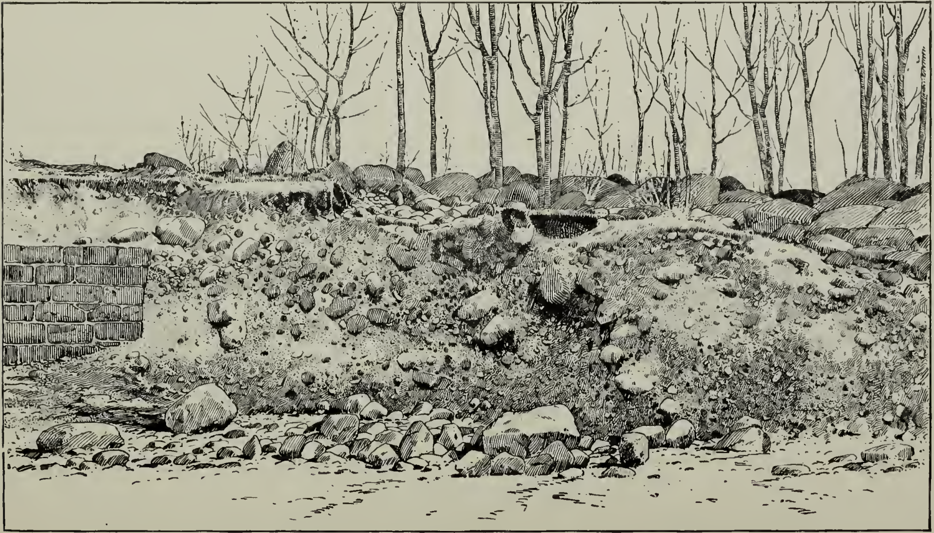
COMPOSITION AND NATURE OF GLACIAL MATERIALS.

The composition and nature of the materials in the glacial deposits next deserve our attention. Turning first to the shoved moraine, we notice in the first place that the clay element so common in most glacial deposits exists in very small proportion in these accumulations. The whole of the mass has the washed appearance which indicates the extensive action of water at the time of its deposition, an action which has resulted in removing not only the clay proper, but also a very large part of the fine sand. Whatever be the nature of the rocks on which a glacial sheet operates a very large portion of the detrital matter is reduced to the fineness of clay and sand. Observing the eroded surfaces in this vicinity, we find that not less than three-fourths of the material removed from them has come from the scratches and the polishing which the ice applied to the surface, and not more than one-tenth from the plucking out of large bowlders such as now compose at least half of the shoved moraine on this island and the neighboring parts of the mainland. This forces us to the conclusion that the shoved moraine does not include all of the material taken from the rocks over which the ice moved, but only the coarser parts of that matter, the finer having been carried on to more distant points.

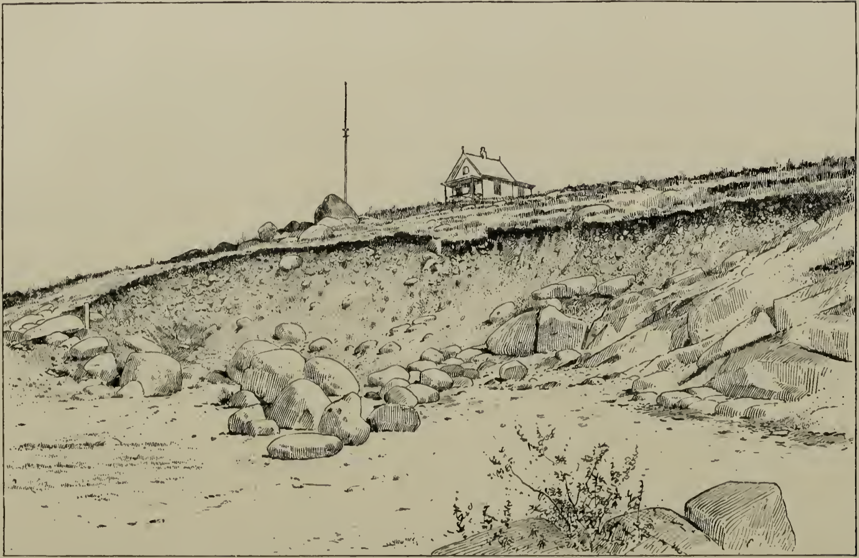
In this field as elsewhere we note that the material contained in the shoved moraine has a more uniform character than that which is found in the two classes of kame deposits and in the frontal aprons. Thus the shoved matter of the great moraines consists, so far as my observation goes, entirely of granitic matter and the fragments of dike stones derived from the intersecting volcanic rocks, while in the materials which are found in the kames we note a very considerable proportion of slaty material as well as of crystalline rocks which are not found on the island of Cape Ann or in the immediately adjacent mainland. In the serpent kames the amount of this waste from sedimentary deposits exceeds five per cent.

The explanation of this peculiarity appears to be as follows: The subglacial streams transported the débris rapidly and under circumstances which exempted it from the grinding action of the ice. These conditions of movement enabled the débris to journey for considerable distances without being ground into the state of powder. On the other hand, the shoved moraine, representing material subjected to powerful attrition, has journeyed for a much less distance, and so these streams have brought to this ground a portion of the detritus worn from the sedimentary deposits which occupy the syncline lying to the northwest of the anticlinal axis which constitutes Cape Ann.

In both the shoved moraine and the kame deposits we find by far the greater part of the material to consist of débris essentially like



SECTION OF FRONTAL MORAINE ON SIDE OF WARNER STREET, GLOUCESTER, MASSACHUSETTS.



SECTION OF FRONTAL MORAINE AT ROCKPORT, SHOWING RELATION TO BED ROCKS.

that exhibited on the surface of Cape Ann. This leads me to the conclusion that crystalline rocks of this axis extend for some miles north of the present shore; a view which is borne out by the character of the rocks exposed in the townships of Essex and also in the southern portion of Ipswich. Both in the kame and in the shoved deposits of this morainal field we observe occasional fragments of gneissic rocks. This waste indicates the existence of a belt of gneiss overlying the injected granites in the country to the north of this district.

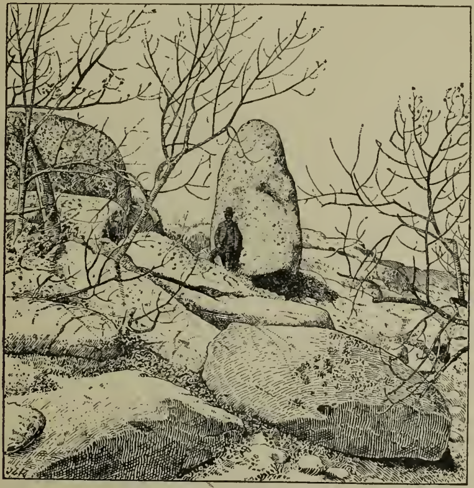


FIG. 42. Perched acuminate bowlder on roadside near Rockport Granite Company's quarry.

The bowlders contained in the shoved moraine usually have a very angular aspect. (See Pls. XLVII, XLVIII, and Fig. 43.) Indeed, no morainal matter of this nature known to me in New England, except at certain points in Maine, exhibits the angularity which we find characteristic of the bowlders in this field. They are also noticeable on account of their large average size. As will be seen from the list of the twenty largest bowlders which have been observed, none of them attain dimensions at all comparable to the greater erratics in other districts. Yet, as will be seen from the figures which give the general aspect of the stonier portions of this moraine, the number of the fragments exceeding a hundred cubic feet in volume is very large. We can frequently find on the surface of a single acre as many as fifty whose average dimensions exceed one hundred cubic feet of mass.

Twenty largest bowlders.

Feet.			Feet.			Feet.			Feet.		
12 by	16 by	6	15 by	14 by	13	17 by	15 by	10	16 by	14 by	14
15	10	9	15	15	18	16	18	11	15	18	12
30	25	18	18	12	11	15	12	9	13	12	10
20	15	14	8	9	6	21	15	13	20	11	13
15	15	12	20	9	11	12	18	14	14	9	16

In the kame deposits we find here as elsewhere that true bowlders are very rare. Those less than a foot in diameter, which have been called by Chamberlain "bowlderets," are not uncommon, though at no point really plentiful. By far the greater portion of the kame material consists of sand, gravel, and pebbles of a rounded form.

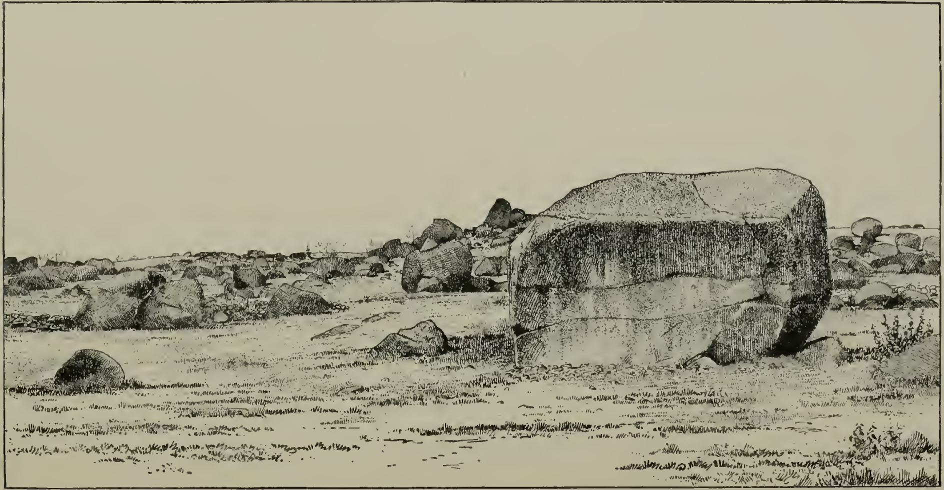
Although the kame deposits are almost entirely limited to the lowlands, we find on the hills of shoved moraine not only the single specimen of serpent kame before noted, but also several small patches of a kame nature, none exceeding three or four acres in extent, and always more or less commingled with ordinary erratics. It is evident that these kame gravels have been imposed upon the surface of the shoved moraine in the form of an overlying sheet.

DECAY OF BOWLDERS.

The extent to which decay has attacked the materials of these morainal accumulations is exceedingly diverse, and affords an interesting subject for inquiry. Within the mass of the kames or shoved moraine the measure of decay is very small. Only a small part of the material exhibits any indication of disintegration. On the surface of the deposits, however, we find extensive marks of corrosion. This process of decay is indicated in two ways:

In the first place, the superficial bowlders are frequently riven by cracks, which follow the natural joint planes of the rock. These crevices are usually opened by the mechanical action of the frost, though they exhibit a certain amount of decay along the lines of fracture. Perhaps one-fifth of the bowlders are broken up in this manner, thus having the surfaces exposed to corrosion very much extended. The figures given herewith exhibit in a clear way the effect of this development of incipient fracture lines. The facts serve also to show us that at the time when these fragments were rent from their bedding places the joints, which have afterwards developed under the action of frost, were completely sealed, affording no lines of weakness or incipient fracture. (See Pl. XLIX.)

There is another and yet more interesting form of decay which is in its nature more truly corrosive. A walk over the surface of the shoved moraine shows us in particular parts of it, especially near its western extremity on the island of Cape Ann, frequent cases in



NORTHERN SLOPE OF PRINCIPAL NORTHERN FRONTAL MORAINE, WITH PART OF ELEVATED KAME PLAIN, DOGTOWN COMMONS; LOOKING SOUTH.

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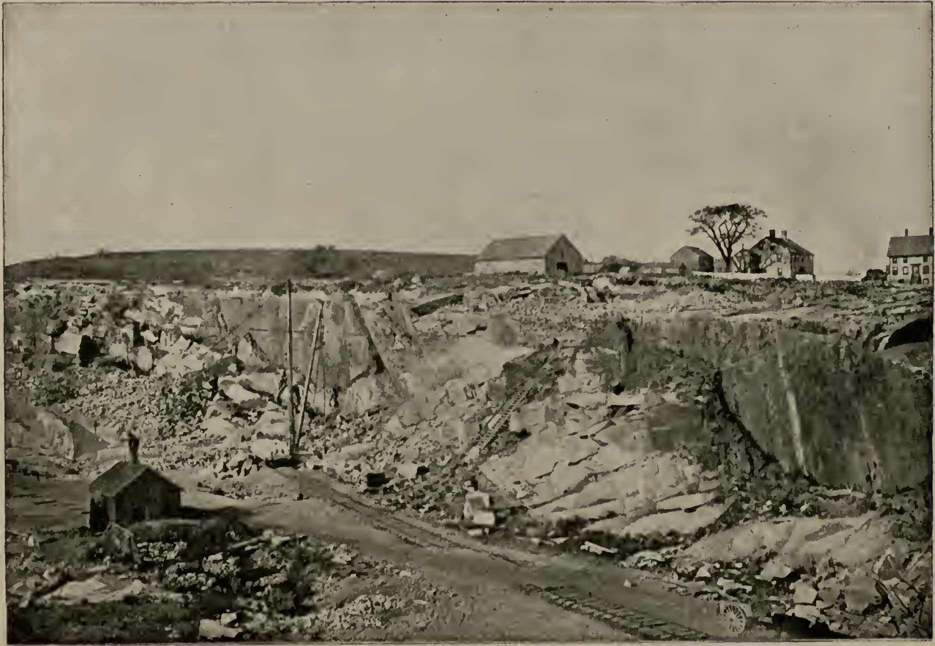


PIGEON HILL QUARRIES; DIKES CUTTING QUARRY ROCKS; PIGEON HILL DRUMLIM IN THE BACKGROUND.

which the bowlders have decayed to a greater or less degree. Sometimes—indeed commonly at the first stages of this corrosive action—the surface of the bowlder which is exposed to the weather remains in a tolerably solid form, while the internal part of the mass has so broken up that the crystals do not adhere to each other. On the under side of the bowlder, where it is partly supported by other erratics, we may note that it is falling into the state of crystalline gravel. Yet further processes of decay may reduce a great erratic to a mass of disintegrating crystals, containing perhaps a core of material, a small fragment of the original bowlder, all the rest having fallen into small bits. A still further stage in the decay may give us a low mound of detritus, over which the vegetation is gradually mantling. Finally, the place where a bowlder contained a mass of one or two hundred cubic feet may appear as a low grassed mound. On some selected areas in the portions of the field where this action is most evident we find that one-fifth or more of the erratics are in an advanced stage of decomposition.

The surface of the bowlder may remain in a measure intact while the interior is greatly decayed. In such cases we generally find that the surface, though retaining at times its original glaciated character, is much riven by crevices, which indicate a process of enlargement of the mass probably arising from kaolinization of the feldspar which it contains. It is readily observed in the field—indeed it is clear from an inspection of the views given in this report—that the bowlders are divided into two distinct groups, those which decay interstitially and those which remain intact. By far the greater part of the bowlders though—even those of very large size, which have never been protected by any kind of soil coating—remain at the depth of six inches below the surface essentially unchanged by the action of the atmosphere. Often they still retain a surface which has probably been little changed since it was impressed by the glacier. Certainly on the average of bowlders more than six feet in diameter the loss in depth of material has not exceeded two inches, and the mass of the bowlder remains as sound as if it were in the original bedding. In several cases, one of which is shown in the figure (see Pl. XLVIII), we observe that a portion of the bowlder has gone to complete decay, while another part remains essentially unaffected by the corrosive forces. We also note the fact that there is no complete gradation between the bowlders which are perfectly protected and those which are greatly decayed. These facts make it clear that the decay is due to some local peculiarity which is found in certain portions of these granites. At first I was disposed to attribute this peculiarity to the chemical constitution of the mass, but close inspection of the material leads me to the conviction that this is not the true explanation of the phenomenon. It is more likely to be explained by the presence or absence of the peculiar close-set joints, which, as we shall note in our study of the structure of the granitites, varies remarkably in different portions of this field. These crevices admit the entrance of water into the mass. The action of frost then produces the same effect upon the mass as it does upon rocks which are penetrated by a slaty cleavage; expanding in the crevices, they are forced somewhat apart, and the way for the penetrating waters made yet more open. (See Pl. L and Fig. 44.)

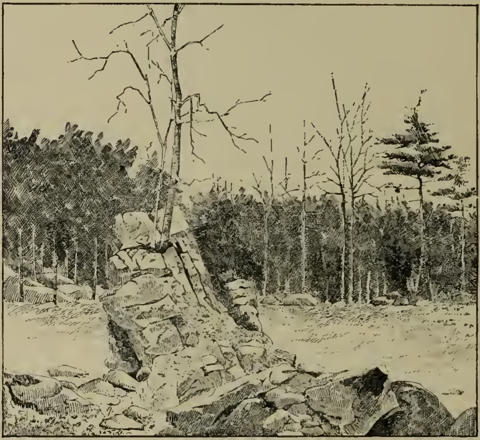
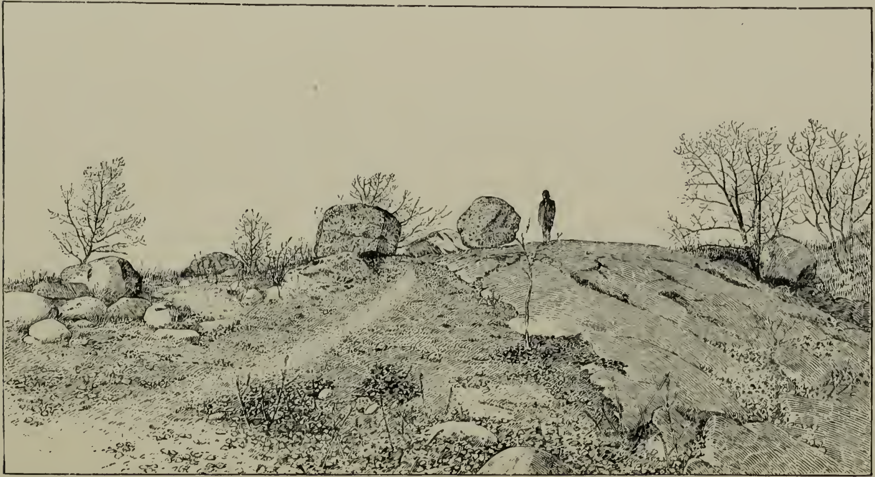


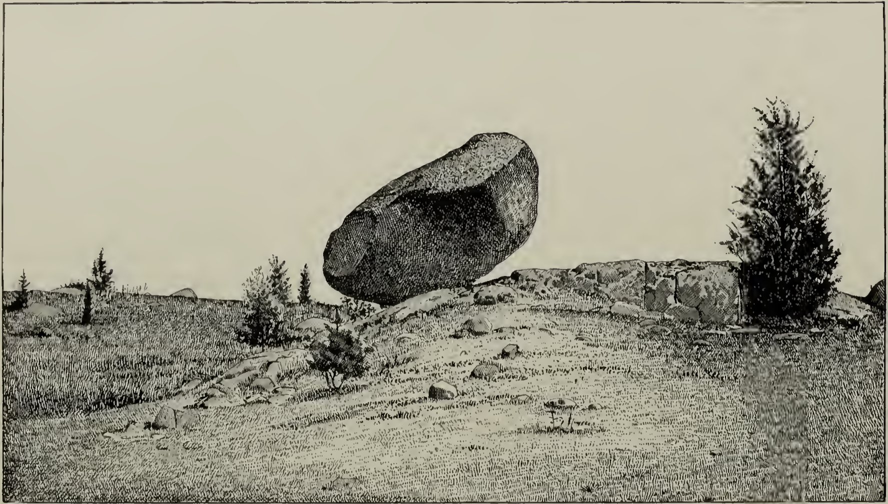
Fig. 43. Bowlder disrupted by action of frost and the roots of trees, midway between Gloucester and Rockport, west side of road.

AMOUNT OF EROSION DURING THE GLACIAL PERIOD.

The general configuration of the promontory of Cape Ann makes it probable that very extensive erosion has taken place in the mass in relatively modern times. It should be noted in the first place from the map, the accompanying sections, and the general description which we have given of this anticline, that it owes its relative relief to the erosion of the synclinal deposits which lie northeast and southwest of the ridge itself. An inspection of the general geology of this district shows us that the synclines which are found in it are generally deeply eroded. That in which lies Boston Bay is so deeply carved as to form a considerable indentation of the shore. A similiar erosion has taken place in the syncline which lies north of Cape Ann ridge, but owing to the fact that the basin is very extensively occupied by drift accumulations, it does not appear as a considerable bay. Yet if this drift material were removed the sea would penetrate as far up the valley of the Merrimac as Lowell,



VIEW NEAR STONE BRIDGE ON THE LINE OF THE EASTERN RAILROAD, ONE-FOURTH OF A MILE NORTHEAST OF GLOUCESTER STATION, SHOWING SOUTHERN MARGIN OF MORAINAL RIDGE.



PERCHED BOWLDER, 13 BY 8 BY 5 FEET, ON SIDE OF ROAD TO COFFIN'S BEACH; GRANITITE BOWLDER ON BED ROCK.

and would occupy a large portion of the field lying to the south of the Merrimac River. The bay would probably be larger than that of Boston, and its surface would, if the drift were thus stripped, be interrupted by only a few rocky islands.

The contour of the surface of Cape Ann, so far as we may judge of it in the present condition of embarrassment from the drift covering, appears to indicate the development in the preglacial period of an extensive system of mountain valleys such as normally form the headwaters of considerable streams. These valleys have been in certain cases deepened and in others been partly destroyed by the action of glacial erosion. Although I am disposed to account for these depressions on the supposition that they have been in a good degree the result of glacial wear, I am inclined to think that this wear served merely to deepen and in part to change the outlines of the original depressions worn by their water.

The general aspect of this topography leads to the conclusion that it could not have originated with the surface of the country at its present elevation above the sea. It appears necessary to suppose that the base level of the erosion was considerably higher at the time when these valleys were developed than it is at the present day. Not only on Cape Ann, but along the whole of this anticline, we find the lower portion of these valleys passing directly below the level of the sea, the submerged portions having been filled in mainly by stratified deposits formed since the close of the glacial period.

The fluviatile origin of these valleys of the Cape Ann anticline is distinctly proved by the fact that they widen and deepen in the natural direction of the drainage. If they were due altogether to glacial action they would not have this form. Still further, the hypothesis that they were produced by the action of free water is confirmed by the fact that in many cases they cut across deposits of diverse hardness in the manner so commonly shown in the action of streams, but unknown in that of glaciers, except where they are confined by the boundaries of pre-existing valleys formed by free water.

GLACIAL SCRATCHES.

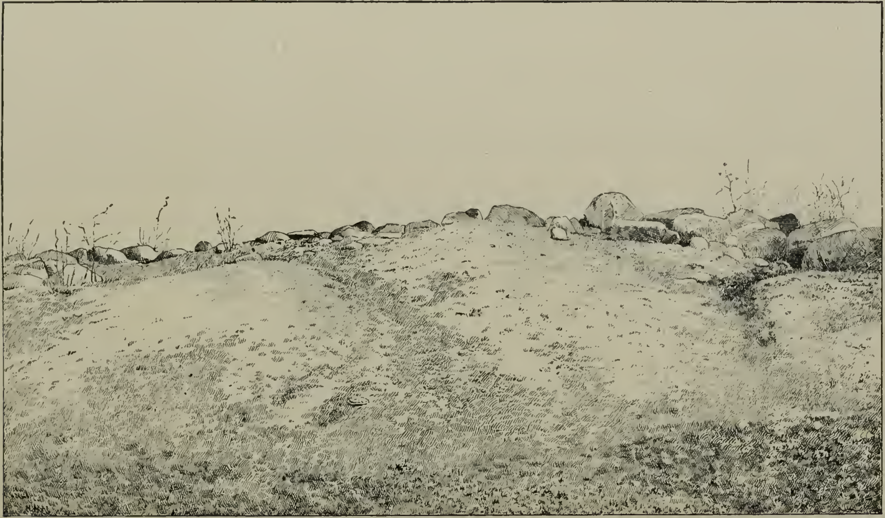
The character of the rocks on Cape Ann, as well as the extensive covering of glacial waste, makes it difficult to ascertain the movements of the ice during the last Glacial Period. Such scratches as have been observed are marked on the accompanying map. They indicate that in general the course of the ice movement was from the northwest or between that point and north. Here, as elsewhere on the coast, the detail topography of the bed rocks evidently affects the glacial movement, so that without a larger number of observations than it has been possible to make in this field we can not determine the general direction of the flow with much accuracy. Some years ago I made observations upon the series of scratches at a locality between Pigeon Cove and Folly Cove, which locality has since been destroyed. Observations show two successive directions of glacial scratches, the one trending from northwest to southeast, the other passing from north to south. Of these the scratches extending from northwest to southeast appear to have been the last formed.

Such variations in the scratches I once deemed of importance as indicating alterations in the direction of the ice movement in the later glacial time. I have observed similar cases along the shore from Eastport to New York. I am now inclined to think that the facts are of small value, for the reason that they show only such temporary alteration in the run of the ice currents as might readily arise from the changes in the strains of a body of such a nature moving over a rough area. The surface of rock on Cape Ann exhibits little trace of the strong grooves which form such a prominent feature in many parts of the glaciated district of North America. The reason for this is tolerably obvious. The hornblenic granitites of this area are very hard; as a whole, much harder than the rocks lying to the northwest, which have afforded the erratics that have impinged upon Cape Ann. The result is that the cutting tool, being softer than the substance to which it was applied, has itself given way. The glacial erosion in this field has been effected rather by the plucking out of large fragments than by the removal of the bed rocks in the finely divided form produced by scratching and grooving.

CARRIAGE OF ERRATIC MATERIAL.

There is a common notion that the drift in New England has generally been conveyed for great distances. The evidence obtained on Cape Ann would of itself be sufficient to disprove this supposition. This evidence goes to show that the detritus in the frontal moraines and till deposits has generally been carried but a very short distance. The average transportation of these fragments probably does not exceed one or two miles. Of the many thousand bowlders which have been inspected probably not more than a dozen are from beyond the field of hornblendic granitite on the island of Cape Ann or the neighboring mainland within a distance of six miles of Annisquam Reach, the exceptional fragments, not amounting to more than a ten-thousandth part, consist of bowlders which were apparently riven from the schistose rocks lying on the north side of the Cape Ann anticline. Two fragments observed, which clearly belonged to the coarse granite, contained large crystals of mica, which is extensively developed in the region about Lowell and Chelmsford. These bits, neither of which exceeds a foot in diameter, may have been carried for a distance of thirty or forty miles.

On Cape Ann, as elsewhere in New England, the kame drift has evidently undergone a more extended transportation than that which belongs to the group of till in the frontal moraine. The kame



PART OF NORTHERN FRONTAL MORAINE, DOGTOWN COMMONS.

(The ungrassed mounds show heaps of crystalline sand left by the decay of bowlders.)

material contains a good deal of waste, perhaps as much as a third of its whole mass, that has evidently been derived from beyond the limits of Cape Ann. The assemblage of materials is substantially that which we find in the drift of the Merrimac Valley. I am inclined to think that a large part of this débris was brought by subglacial streams from that part of the mainland. The proportion of material in the kame gravels derived from distant sources appears to be greater in the case of the serpent kames than in the other deposits of stratified gravels.

POST-GLACIAL EROSION ON CAPE ANN.

ATMOSPHERIC EROSION.

The post-glacial erosion of this district may be divided into two classes—that which is due to the action of surface water, and that which has arisen from the work of the sea on the coast line, both at the present level and at times when the shore was higher.

Considering first the atmospheric erosion, we find that in the main it has been exceedingly small. The area of Cape Ann is not sufficiently great to bring about the accumulation of the fluviatile waters in large streams. The considerable thickness of the drift mass in the upper parts of the island causes the discharge of water to be very regular, and the great prevalence of large bowlders restricts the cutting action of the brooks. Owing to the fact that the bowldery drift contains but little clay, the water penetrates deeply into it and is there stored, to be emitted in a very gradual manner. The frontal apron of the moraine lies almost altogether below the surface of the sea. Therefore this region wants the element of a glacial topography which is most readily cut up by flowing water.

The existing streams on the island, all of them of small size, occupy almost altogether valleys that are in no wise due to their own action, but have been formed by the accidents which have determined the position of the glacial drift. They generally lie in the lines between the morainal ridges, or, where those ridges are wanting, in the channels in the bed rock, which were worn to their present shape if not altogether formed, by the action of the ice. At certain points on the surface of the moraine, particularly on the southern slope, though occasionally occurring also upon its northern versant, there are narrow V-shaped valleys, somewhat clogged with bowlders, which appear to indicate the former existence of streams which were much more powerful than those now operating on the surface. I am inclined to believe that these channels may be due to the fact that in the time immediately following the dispersion of the glacial sheet from this surface and its re-elevation the rain-fall was much more considerable than it is at present. It is, however, impossible to make certain that these channels were not formed by tongue-like protrusions of the ice, which scoured away the portions of the moraine which they traversed. It is true we do not find the heaps of eroded material which in other places often mark the action of such protrusions of the ice, but it is likely that these heaps lie beneath the surface of the sea.

On small areas of the frontal apron and kame sands which remain visible on Cape Ann we find a few shallow runnels, which have doubtless originated from the scouring action of the waters which now flow through them. These channels are, however, so insignificant as to merit no particular description. The only noticeable feature concerning them is that they extend to the present shore, with an inclination which shows that they have been lowered below the sea level in comparatively modern times.

MARINE EROSION.

The erosive action of the sea presents us with much more important phenomena than that which is due to atmospheric causes. Leaving for the present the question of the action of the sea at former levels above its present height, I shall now consider the effect upon the coast line of this district of the waves and the other erosive agents derived from the ocean.

The whole of the shore line of Cape Ann and that of the larger part of the mainland included within this report, except where small parts have been filled in by drifting sand and pebbles, lies upon the hard crystalline rocks which entirely compose the basement deposits of this region. On these rocks the ocean has exercised its usual erosive influence, due to two diverse causes. In the first place, the assault is accomplished by the beating action of the waves operating upon the cliffs by means of the fragments of rock which the surges impel against the shore. The work of erosion has also been greatly aided, at least in recent time, by the action of ice, which forms abundantly along the whole of this coast line, and operates in a way to advance the disintegration of the hard rocks.

The diversity of the effect of the waves upon the shores is very great. The measure of this action is greatly influenced by the structure of the rocks as regards the joint planes or incipient rupture lines which they afford. Where the rock is abundantly rifted, frost, acting upon the water which has penetrated the crevices, as is well known, breaks up the continuity of the mass. Again, the action of the waves is diversified in its measure by the character of the slope with which the land meets the sea. Thus where, as at several points, the shore descends abruptly into deep water, the waves are not armed with detrital matter, which by being impelled against the cliffs, serves to cut away the rock. Such cliffs are usually unaffected by the blows of the waves, and remain essentially unchanged as regards the outlines given them by glacial erosion. Pls. XXXVII and LII show the action of the sea under these circumstances.

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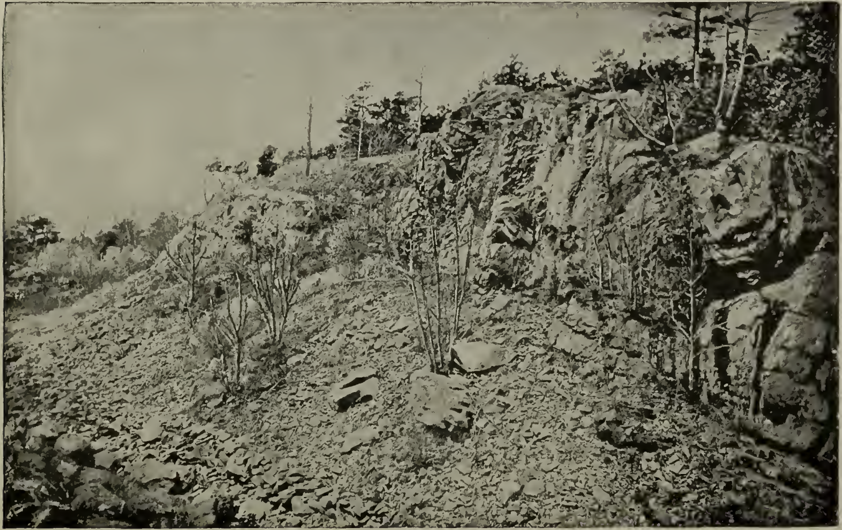


POST-GLACIAL TALUS OF GRANITE PORPHYRY AT WEST GLOUCESTER, LOOKING NORTHWEST, SHOWING RAPID DESTRUCTION OF ROCK BY FROST ACTION.

Where, however, the submarine foundations of the cliffs are in water not more than thirty feet deep, such bowldery matter as may lie at their base is within the grip of the waves and is used by them for the assault of the cliffs. At certain points, where there is a compact detrital talus sufficiently near the surface of the water to admit of effective wave action against the fragments which lie on it, the action of the sea is such as to sweep away from the base of the promontory all the masses which accumulate there, and so protect the cliff against the attrition of the waves. The erosive action of the sea is the most effective where, as on the shore just east of Salt Island, the joints of the rock are so disposed that the frost may rive out the fragments and put them in control of the waves. At such point the sea has generally formed a distinct bench in the manner shown in Pls. XXXII and LIII.

Considering the shore as a whole, not more than a tenth of its line exhibits marine benching of a distinct character. On by far the greater portion of the line the original glacial form remains, with the exception that here and there a small portion of the material has been scarfed away by the combined action of waves and ice. Pl. XXXII exhibits the usual manner in which the line of coast meets the sea.

At first I was disposed to believe that the exemption from erosion was due to the fact that the rocks next the shore had originally been protected by a thick coating of drift, upon which for a time the energy of the waves had been expended, but on closer inquiry I find that the morainal matter of the island, though very thick in the interior district, is very thin next the shore. In a word, this distribution indicates that no considerable mass of such material at any stage of the history of the region since the sea attained its present level lay along the coast line. I am therefore forced to the conclusion that the absence of the marine bench is due in part to the brevity of the time in which the sea has operated at its present level and in part to the fact that the attitude and condition of the coast rocks is such as to afford the coasts a large measure of protection against wave action.

Where the original slope of the rocks towards the sea was very gentle, the waves, in place of striking a violent blow against them, slip up over their surfaces, producing a mere swash in place of an effective stroke. In this case the erosion may take the shape of scouring, as is shown on Pls. XXXIV and XXXV. Even where the rocks descend towards the surge with a steep angle, their structure must be jointed in a manner favorable for the action of the ocean surges, and there must be a talus at the proper depth beneath the surface to favor the movement of the erratics when flung by the waves against the cliff. These several conditions do not exhaust the category of the circumstances which affect the erosion of the shore. Where the rock is much penetrated by dikes, these dikes are almost invariably less resistent to erosion than the country rock which bounds them, so the result is that under the operation of erosive agents—frost and waves—they become chasms, which serve to weaken the coast wall even where it is not otherwise enfeebled, and so bring about an extensive erosion of the shore. Examples of such action are shown in Pls. XXXIV, LIII, LIV, LV, and LVI.

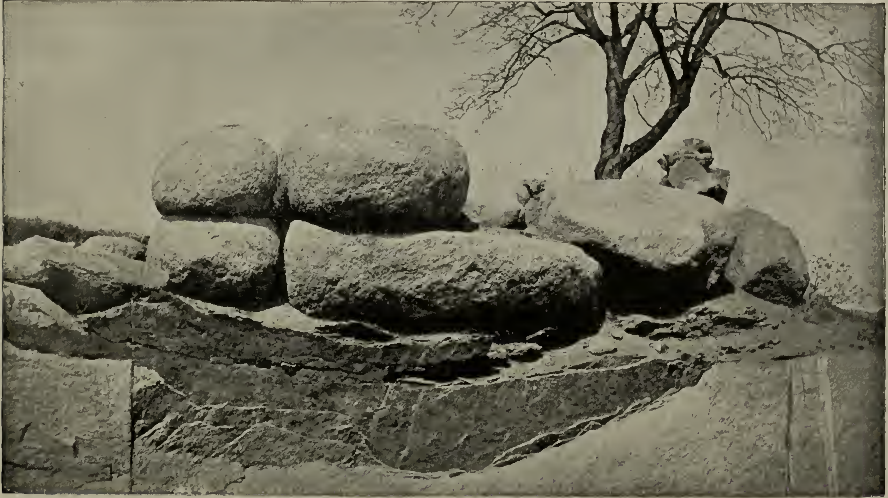
It is now necessary to consider not only the scarf which has been formed along the coast, but also the re-entrants or bays plentifully distributed along its line. Although not so diversified in outline as the neighboring coast of Maine, though formed of similar rocks, the Cape Ann coast presents us with numerous small fiord-like embayments. The reason for this difference is probably to be found in the fact that the strike of the obscurely separated granitic masses on the surface of Cape Ann is nearly northwest and southeast, or in general at about right angles to the flow of the ice; while on the coast of Maine the strikes are more nearly north and south, while the run of the ice is nearer to the meridional line than on this part of the Massachusetts shore. It is clear that the fiords are more easily formed where the strike of the strata coincides with the run of the ice than when these strikes run in the opposite condition.

The fiord structure of Cape Ann is in nowise due to the action of the sea, though these re-entrants have, as we shall shortly see, an important influence on marine action. The fiords of Cape Ann are probably due in part to ordinary fluviatile erosion acting upon rocks according to their resistance and in part to the wearing action of the ice sheet.

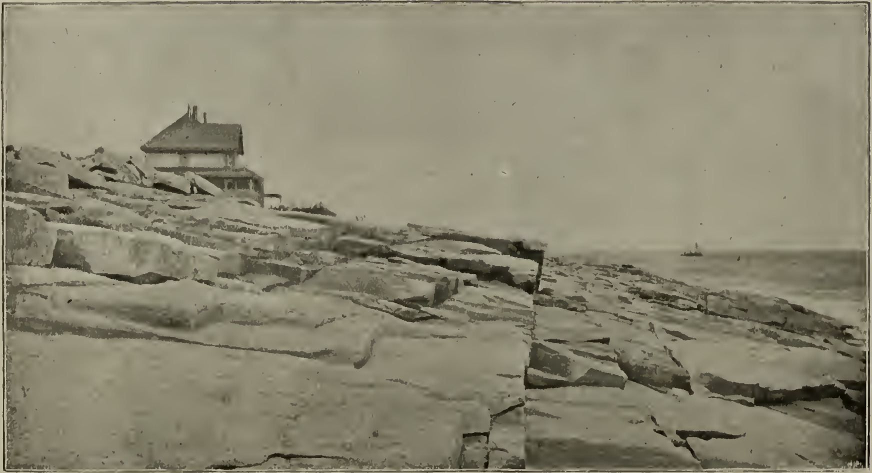
SEA BEACHES.

The effect of the above-described bays is to afford a place of deposit for the material worn from the headlands or brought in from the sea. The structure of one of these beaches is indicated in Plate LVII. On the coast line of Cape Ann and the neighboring mainland included within this report there are about twenty-five of these re-entrants in which beach deposits composed of materials derived from marine action have been accumulated. On the average there is one such pocket to about each mile of shore, and on no part of the marine front do we find these accumulations absent for more than two miles.

The manifest effect of these beach accumulations is in an important manner to limit the erosive work done by the pebbles under the influence of the waves. If a pebble or bowlder is retained on the cliff front until it is ground to powder, all its resistance to the blows is turned to account by the waves in the work of wearing the cliffs; as soon as it is impounded in the beach, it ceases to have any value as an erosive agent. Although it may be ground to powder upon the beach, its force is expended upon the neighboring peb-



DECOMPOSITION BOWLDER IN PLACE, LANESVILLE GRANITE COMPANY'S QUARRY, EASTERN SIDE.



SHORE AT PIGEON COVE, SHOWING EFFECT OF NEARLY HORIZONTAL JOINT PLANES WHEN WORN BY SEA WAVES; LOOKING NORTHEAST.

(The fragments at the top of the slope have been thrown up by the waves.)

bles and not upon the cliffs from which it may have been derived. The difference in the amount of erosion brought about by this variety in the history of a pebble is of considerable importance in the economy of the shore. So numerous are these pocket beaches on Cape Ann, that in most cases the masses of rock derived from the erosion of the cliffs remain for but a short time available as instruments of wear when hurled by the waves; they quickly find their way into the nearest pocket beach. (See Pl. LVII.)

The peculiar salience of the island of Cape Ann favors this rapid impounding of the pebbles. The waves run with considerable energy from a great variety of directions. They are effective on all points from the northwest around by the east to the southwest. Thus, if a pebble is held against a shore having a north and south direction by all the winds blowing from the east, the waves running during the northeast and southeast storms will tend to work it along the coast towards the nearest pocket beach. The result of this action is that the pocket beaches of the Cape Ann district contain a very much larger amount of detrital matter than has been eroded from the cliffs since the sea assumed its present altitude, much being brought from the regions north and south of the district.

EFFECT OF SEA-WEEDS ON MOVEMENTS OF PEBBLES.

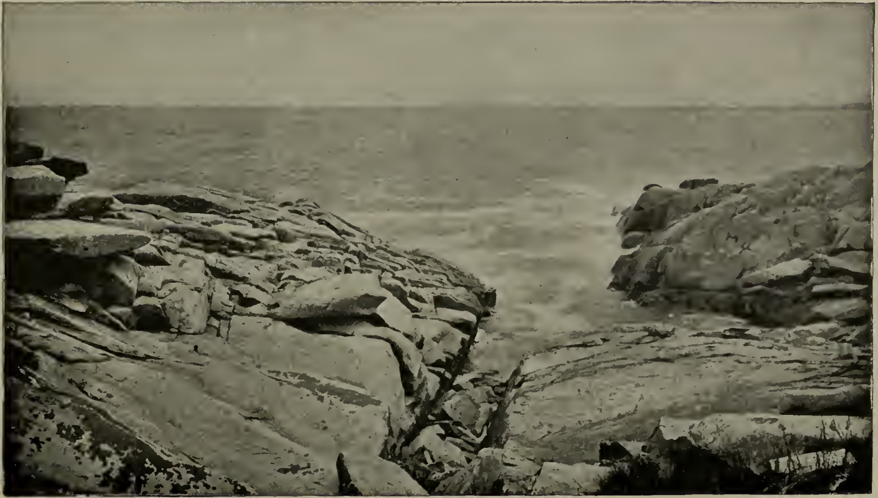
The large amount of the accumulations of impounded matter in the various bays is due in part to the fact that a considerable quantity of glacial detritus has been brought in in the form of pebbles or bowlders, not exceeding a foot or so in diameter, from the deposits of such materials lying upon the sea floor. These deposits, accumulated on the sea bottom, were formed in the main during the time when the shore was at a higher level than at present. At first I was disposed to consider that the material worked in from the sea altogether, because of the fact that the recent elevation had brought the bottom so near the surface that the waves eroded the floor over which they traveled and moved the waste in towards the shore. More careful study has satisfied me that this scouring action of the waves acts only upon the sand and perhaps on pebbly matter less than an inch in diameter. The large ingress of pebbles and small bowlders must be explained in another manner.

The sandy accumulations, particularly the extensive deposits formed in Sandy Bay, on Long Beach, around Little Good Harbor beach, Brace's Cove, and other points of the shore, are clearly due to the scouring action of the waves operating on the neighboring parts of the sea floor. The pebbles, at least those above an inch in diameter, are in the main brought to the coast line in a manner which I will now describe.

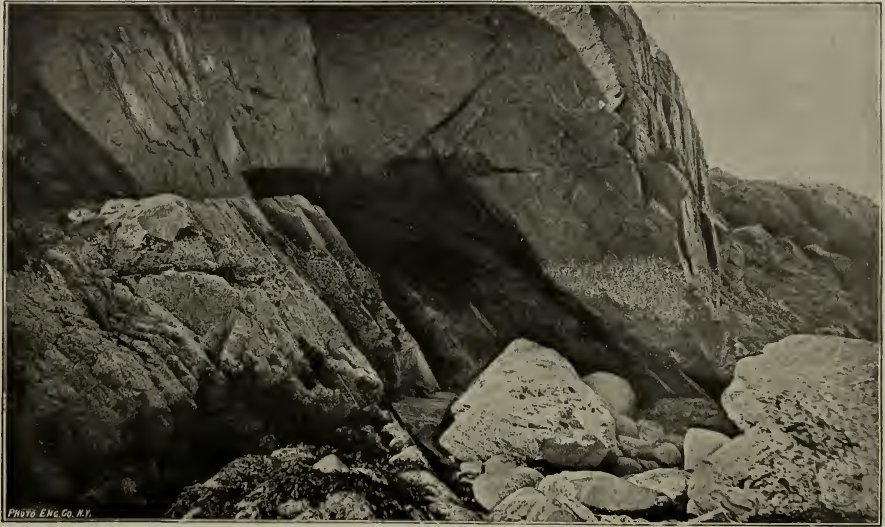
The bowlders and larger pebbles, as they lie upon the sea bottom, not only by their weight oppose the movement of the waves which tend to urge them towards the shore, but they are attached to the bottom by the adhesion naturally resulting from long continuance in their place. Even where the waves are strong enough to roll them if they were free from these attachments they remain immovable. It is to the growth of sea-weed upon their upper surfaces that we owe in most cases their detachment from the bottom and their ready transportation to the shores. When the sea-weed becomes attached to these pebbles its continued growth leads in time to the separation of the pebble from the bottom. This is brought about partly by the impulse to float due to the relative lightness of the plants, and in a larger measure through the pull which the waves are enabled to make on the expanded fronds of the sea-weed. When, in time, through the growth of the plant, this pull becomes strong enough to detach a pebble from its ancient fastenings, it rises a little way above the bottom, sometimes floats freely, sometimes just rests on the sea floor, and so impelled by the waves begins the journey towards the shore, which becomes more rapid the shallower the water to which it attains. Finally, it is brought into the mill of the surf; it then in most cases becomes separated from the plants which brought it ashore and appears as an ordinary pebble upon the beach.

Choosing a time when the surf is high, we may note a great quantity of sea-weed on the beach. Each of these weeds shows in its expanded root-like base that it has recently been severed from an attachment to some rock. Occasionally we find a pebble to which the sea-weed is still clinging. These are rarely abundant, for the reason that the separation, as before noted, has usually taken place by the pounding of the surf; but at times it is possible to gather a bushel of these pebbles still attached to the sea-weed within the distance of one hundred feet of shore line. If an observer in a time of storm will follow a retreating wave outward, so that he may have an opportunity to observe the inner face of the surf wall when it rises in its steep form a moment before the overturn of the wave, he will, if quick-eyed, be able to note in the transparent water many of these sea-weeds as they are lifted to a vertical position by the uprising of the wave. Furthermore, if he will journey in a boat beyond the surf line, he may find many of these sea-weeds floating with the tops at the surface of the water, each bearing at the base a pebble or large shell, which have been plucked from the bottom some distance from the coast line.

Although the quantity of this pebbly matter brought in by any one storm is not very great, the contribution is repeatedly made, so that during each year perhaps in a score of storms some tons of bowlder material comes upon the shore within the length of a thousand feet. A portion of these bowlders with their floats of sea-weed are of course driven against the cliff portion of the shore, where the



WORN-OUT DIKE ON SHORE OF PIGEON COVE, SO-CALLED "CHAPIN'S GULLY;" LOOKING SOUTHEAST.



SEA-CAVE ON SHORE OPPOSITE SALT ISLAND, SHOWING PROCESS OF WAVE EXCAVATION ON JOINTED ROCKS.

bowlders serve for a time in the work of the waves, but they shortly find their way into the re-entrants in the manner before described.

Not only do these sea-weed-borne fragments contribute much, perhaps a greater part, of the waste to the beaches, but in certain cases they form considerable pebbly islands off the coast. Thus, Milk Island, south of Thatcher's Island, though its central parts are of bed rock, is mainly composed of these pebbles, removed from their bedding by the sea-weed and intercepted on their journey towards the mainland by the shoal formed by this glacially rounded mass interposed in their path.

RATE OF WEAR OF PEBBLES.

The rate at which the beach pebbles wear varies of course with their size and with reference to the conditions of exposure to the surge. The smaller the pebbles, the more rapidly they are worn, for the reason that they are more readily stirred by the action of slight waves. Thus, pebbles two inches in diameter are set in motion even when the sea is nearly calm, while those a foot in diameter are probably not in motion for more than one-half of the year, and those which exceed two feet in diameter are only knocked about in the greater storms. We must reckon on the fact that the larger pebbles strike harder blows than those of small size, but I am inclined to think that the rate of wear between those one foot and one inch in diameter is generally proportionate to the difference in the mass.

It is interesting to note that no considerable part of the mud produced by the wearing of the pebbles on these beaches remains visible. By far the greater portion is evidently drawn away into the depths of the sea by the undertow which during high winds prevails along every shore.

The wearing action even on the larger pebbles is evident from observations which can readily be made on the masses of riprap used for the defense of the moles which inclose the small artificial harbors between Rockport and Pigeon Cove. Although originally of very angular forms, such as plentifully occur in the quarries, an exposure to the full beating of the waves serves even in a single year to bring about a considerable rounding of the mass. In ten years they commonly wear away to the rolled form so familiar in our beach pebbles. Under favorable circumstances it is evident that the wear upon the pebbles amounts on the average to several inches per annum. We thus obtain a rough measure of the rate at which the surges are able to bring about the wear and consequent rounding of detached masses.

It should be remarked, however, in this connection that the rate at which these artificially exposed angular masses become rounded is somewhat greater than that which occurs in masses detached from cliffs, for the reason that under the conditions in which they are placed the sea has a peculiarly favorable opportunity for attacking them. Their position is extremely exposed, and many fragments are associated together in a manner which causes them to rub against each other more energetically than is possible at the foot of an ordinary cliff.

In seeking to find stone suitable for quarrying purposes, explorers have opened small excavations on most all the headlands around the periphery of Cape Ann. These have discharged into the sea a large quantity of angular blocks, which have been moved along the escarpments until impounded in some beach pocket, where they are now in the process of rapid erosion. Blocks of this nature can be readily separated by the eye from those which have been ruptured from the cliffs by the action of the waves and frost, for the reason that bowlders formed entirely in the natural way are generally discolored by decay to a greater depth than corrosion has penetrated, while those formed in an artificial manner usually retain the blue-gray hue of the ordinary quarry stones.

Using this means of discrimination in order to separate the artificial from the natural pebbles, the observer can readily make an eye-estimate as to the relative amounts of bowldery matter formed by natural and artificial means. He will perceive that the amount of detrital material formed in the natural way on rocky shores is often less considerable than that contributed by the process of quarrying. A number of little pocket beaches filled with bowlders which are found along the coast, especially between Loblolly Cove and Halibut Point, are almost entirely composed of rounded waste from the quarries.

The ineffectiveness of marine action on certain parts of the shore is particularly conspicuous. Thus near Pigeon Cove (See Pl. LII) it is evident that marine action has since the Glacial Period not removed in average thickness more than one or two feet of the rock which forms the shore line, while in the region immediately south of Bass Rocks the erosion is perhaps thirty times as great. The cause of this variety in the amount of wearing is readily found in the difference of original inclinations of the shore towards the sea. At Anderson Point the rocks have a very gentle slope towards the waves. The surges working on the coast line slip up over this slope and expend their energy in lifting the mass of water above its base. Where, as at Bass Rocks, the shore meets the sea at a steeper angle, the direct blow of the waves is struck against the cliffs and operates much more effectively.

The concomitant in this action is found in the extent to which the shore at these diverse points is affected by dikes which are readily worn out by the water. Near Bass Rocks and also near Straitsmouth Island the dikes are numerous and readily attacked by the waves. (See Pls. XXXIII, LIII, LV, LVI.) When the dike material is re-

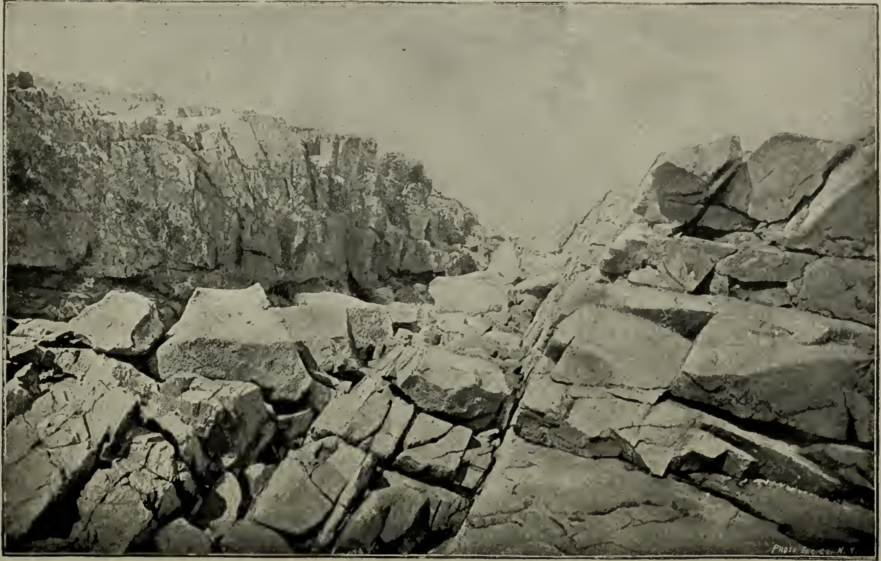


Photo. Eng. Co. N. Y.

CHASM ABOVE HIGH-WATER MARK, FORMED BY EROSION OF DIKE, ROCKPORT POINT, EAST SIDE.

moved steep cliffs are left on either side in positions to be open to the assault of the sea. This effect is well seen on the shores just inside of Straitsmouth Island, known as Gully Point, where the dikes, being rather softer than elsewhere, have been deeply excavated by the waves.

DECAY IN ROCKS IN PLACE.

I have already noted the fact that the bowlders contained in the frontal moraines are in many cases extensively decayed. So far has this decay gone, that I have often found a bowlder which was originally six feet in diameter represented by a low mound of angular sand upon which the vegetation finds root. The same decay, though in much less striking form, is exhibited by the rocks in place. So far as my observations have gone this decay is limited to the granitites, not affecting the dike stones. It generally occurs within 10 feet of the surface in sections where the rocks lie in a position which favors the penetration of surface water. Finding its way along the joints, the water furnishes conditions of corrosion, so that from the joint planes the decay penetrates to a greater or less distance into the unrifted portion between the fracture planes. A portion of the material is reduced to the state of sand, another part is merely discolored and weakened by the oxidizing process. (See Pl. LI.)

In passing, I may remark the fact that the considerable penetration of this form of decay since the Glacial Period affords, when taken in connection with the decayed bowlders above referred to, important evidence as to the depth to which the glacial erosion operated during the last ice time. It is evident that the decayed bowlders were not affected by the corrosive process before they entered on their journey towards the front of the ice field. The strains to which they were subjected in that journey would have led to their destruction if they had not been of very solid rock. In order to obtain bowldery matter liable to corrosion and at the same time not decayed, the glaciers must have removed all the superficial parts of oxidized rocks which existed on the surface at the time their work began.

There can be no question that the decay in certain of the bowlders is generally more complete than that which has occurred in any rock in place. This is readily explained by the fact that the bowlders are much more favorably placed for the work of corrosion than are any portions of the rocks in their original position.

RECENT CHANGES OF LEVEL IN THE CAPE ANN DISTRICT.

As one of the principal objects of the series of monographs descriptive of different parts of the Atlantic coast which I have undertaken is to determine the recent changes of level which have occurred along that shore line, I turn with interest to the study of post-glacial changes in the altitude of the land on this part of the coast.

My studies on the island of Mount Desert have apparently shown that on that shore, one hundred miles north of Cape Ann, very remarkable alterations of level have taken place since the close of the Glacial Period, or at least since the disappearance of the ice sheet from that portion of the coast. On Mount Desert the evidence indicates movements of elevation since the disappearance of the ice, and on other parts of the shore from Portland southward the evidence is to the effect that the movements have been in part in the direction of subsidence and in part those of elevation. On Mount Desert itself all the observed facts indicate elevation alone, though, as remarked in my memoir on that island, published in the Annual Report of the Director for 1886-'87, the shore of Mount Desert is very unfavorably placed for the preservation of evidence of subsidence. It may therefore well be the case that subsidence has taken place there, though the proof of it is wanting.

EVIDENCES OF RECENT SUBSIDENCE.

Considering first the evidence of recent subsidence, we find on Cape Ann a limited but important set of facts which bear on this problem. On the east shore of the island, at a point indicated on the map by the words "submerged forest," near the isolated mass of rock known as "Briar Neck," we find between high and low tide mark a number of tree stumps with their roots still fixed in an ancient soil in their normal positions, which clearly indicate a very recent subsidence, amounting to as much as four feet of actual height. These interesting remains lie in a position that appears to me to exclude any other hypothesis than that which assumes that the surface on which they stand has been lowered by a downward movement of the subjacent earth. They stand upon a nearly plane surface, in front of a low beach wall of sand and pebbles; behind them lies a considerable area of marine marshes.

In this and the numerous other cases of depressed forests which occur on our shore the hypothesis which has been suggested, that the sea has undercut the soil in which the forest grew, thus lowering it beneath its present position, appears to me quite untenable. The waves strike against this shore with great energy. As soon as the stumps are separated from the enveloping beach sand they are quickly cut away by the surf. The process of undercutting which should lower the forest bed to the level of the waves would necessarily lead to the immediate destruction of the deposit. Moreover, here as elsewhere, we ask the question as to where we may now find this process of undercutting in operation? If we account for the submerged forests on this theory, we should be prepared to show

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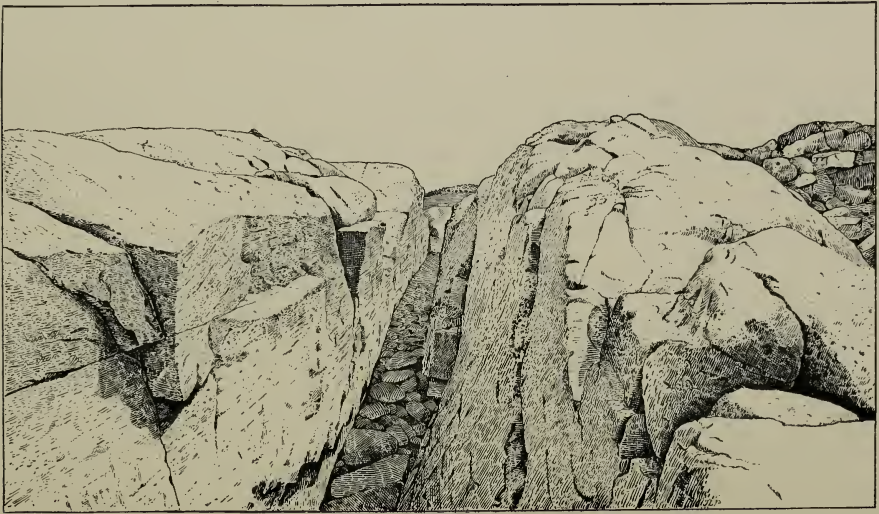

DIKE CHASM ABOVE HIGH-WATER MARK, WEST SIDE OF ROCKPORT POINT, SHOWING DIKE MATERIAL CONVERTED INTO BOWLDERS.

along our extensive shore line instances in which it may be seen in various stages of accomplishment. My studies on the Atlantic shore line have shown me in a very detailed way the greater part of the coast between Eastport and New York. At no point have I ever observed any process of undercutting the forest such as this hypothesis demands. I therefore take this example as well as the numerous others which occur along our coast as complete evidence that a recent subsidence of the shore or elevation of the sea to the amount of several feet has occurred in very modern times.[1]

So far this is the only instance on the periphery of Cape Ann where I have been able certainly to ascertain the existence of submerged forests. It is to be observed that the conditions which permit the preservation and the re-elevation of such deposits are peculiar. Except where shown by artificial excavations, we find them at points where the sea cuts through a mass of dune sand such as forms along the coast line or sand of the beach, in which the remains of the forest lie buried. Where a beach is gaining on the sea, as is the case with most of the sand beaches of the Cape Ann district, we can not of course expect to gain any sight of a submerged forest existing at that point. It is only where the sand beaches are retreating landward that the buried forests are likely to be exposed to view.

Although the existing remains of the submerged forests above referred to prove at most a subsidence of four or five feet, there is good reason to believe that the total amount of this depression has been much greater than is indicated at this place. In the adjacent waters of Massachusetts Bay we find on the flats of Lynn Bay occasional stumps of trees faintly exposed to view through the water at the lowest run of the tides, and in Cambridgeport, Mass., I obtained the stump of a tree in position seventeen feet below high-tide mark, or about seven feet below the lowest tides of the present day.

EVIDENCES OF RECENT ELEVATION.

The evidences of recent elevation along the coast of Cape Ann are extremely obscure, at least when compared with the proof of such movements afforded on the island of Mount Desert. The proofs which we may obtain of the temporary sojourn of the sea at heights above its present level fall into the following classes: First, we may have a surface swept clear of all but the larger bowlders in the fashion shown along the present shore line. This effect may be looked for even where the sea operated on the surface for a very brief time, provided the drift coating was not extremely thick. Where the surface has been scoured in this fashion by the waves the drift is not only removed from the convex portions of the area, but is scoured out of the crevices and clefts of the rock, in which it is sure to remain where the waves have not washed their surfaces. Thus, such rock areas as are shown in Pls. XXXIII, XXXIV, LVIII, LIX, LX, LXI, and Fig. 45, clearly indicate the action of the waves by the complete removal of the detrital material which has accumulated at their base in the form of a gently sloping talus.

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[1] See memoir on Martha's Vineyard, Annual Report U. S. Geol. Survey for 1885-'86; also report on Geology of Nantucket, Bulletin of Geological Survey, No. 53.

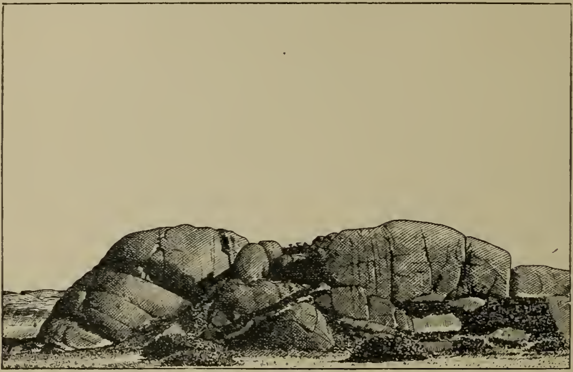
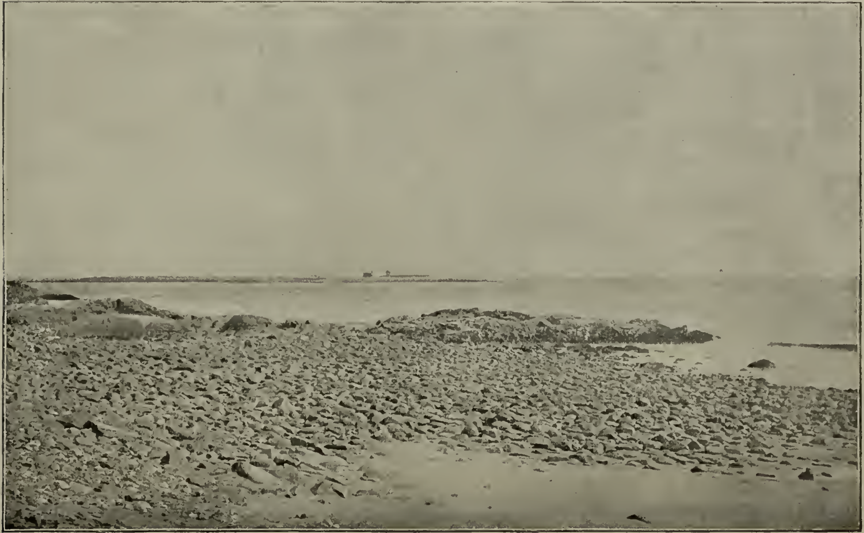


FIG. 44. Eastern Point, 40 to 70 feet above sea; ledges from which drift has been completely removed by marine action.

Where the waves operated for a considerable time on the surface, we may expect to find the softer parts of the rocks, the portions enfeebled by the numerous joints or by dikes, distinctly excavated, forming chasms or sea caves according to the direction in which the lines of weakness extend. The amount of this distinct cutting action depends largely on the slope of the rocky surface; as we see along the existing shore where this slope is very gentle the sea has practically no cutting power, whereas if the original slope was steep, the cliff and bench, such as shown in Pl. XXXIII, quickly formed. Again, where the process of erosion has continued for a considerable time the waste removed from the salients will be accumulated in the form of beaches in the interior portion of the re-entrant angles. The accumulation of beaches appears to require a more continued action of the sea than is needed for the formation of the other indices of marine action.

It is important to notice that where the drift coating is thick the natural processes which affect the movements of the soil after the passage of the sea from the surface at once operate to destroy all marks of wave action upon the surface. Although a scarf may be cut in the detrital matter, and perhaps in the solid rock upon which



NORTHEAST END OF BEACH NEAR CAPE HEDGE, MILK ISLAND IN DISTANCE, SHOWING TYPE OF BOWLDER BEACH.

it rests, no sooner does the sea disappear than gravity, aided by the action of frost and by the action of trees which by their expanding roots shove the masses downwards and in the cases where the trunks are overturned by winds displace large masses of the material, serves quickly to heal the slope, so that in a short time the bench may be entirely effaced. This action is so manifest on the surface of Mount Desert that I have long since ceased to put much trust in indications of marine action derived from faces of loose material, though it can not be denied that traces of such erosion may be found on the flanks of some of our drumlins.

HEIGHT OF SEA SINCE GLACIAL PERIOD.

The imperfect evidence which I have succeeded in obtaining on the Cape Ann district, serving to show the action of the sea above its present level, is limited to 150 feet above the present tide mark. Within this section the evidence consists mainly in the removal of the drift from extensive areas of rock on which it was originally thinly distributed.

Where, on a large area, we find no glacial debris except occasional bowlders with the dimensions of those which now resist the action of the waves along the shore, we may be pretty sure that the sea has not acted, and this for the following reason, viz: On any surface which has been glacially eroded, as has the whole of the Cape Ann district, the ice as it passed away must have left a thin sheet of detrital materials. Even where the surface was more or less washed by the melting waters of the retreating ice, the crannies and hollow places of the rock surfaces would necessarily contain a good deal of glacial waste which would escape removal. I am unable to explain a complete scouring of the surface, such as is exhibited in Pls. LIV and LIX, without having recourse to wave action.

The argument in favor of wave action becomes stronger when, as before remarked, we find the steeper faces of the rocks worn by the work of the sea in the fashion that can be effected only by the battering action of the surges. It is usually easy in case of any strongly projecting mass of glacially eroded bed rock to determine which of its several versants would have received the direct beating of the waves and which would have been protected from their action. If, on the faces which would have been exposed to the ocean surges at the time when the sea is supposed to have stood at the higher level, we find a recognizable amount of marine erosion, we substantiate the hypothesis which supposes the original greater height of the sea.

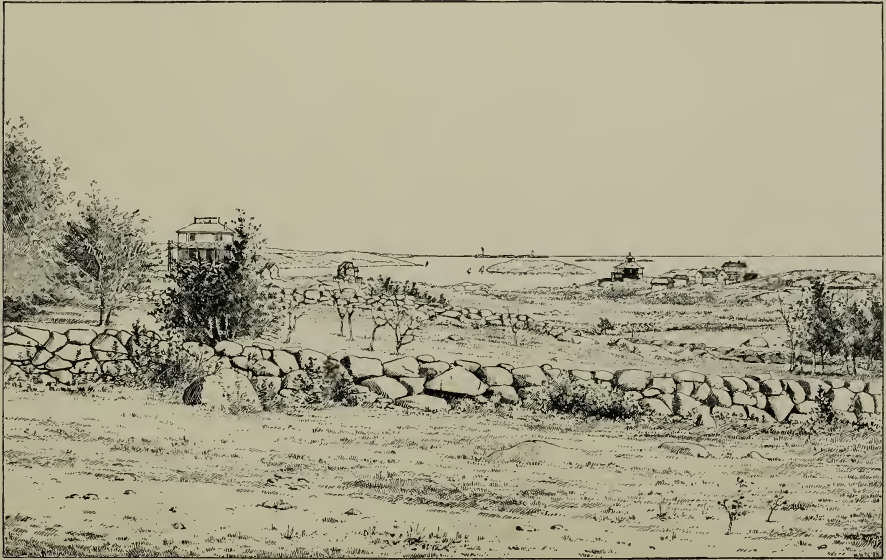
Beginning at the present level of the sea, we first note the fact that the recent slight uplift has raised the shore to the amount of something less than ten feet. This is shown by the conditions prevailing in many of the clefts along the shore which have evidently been eroded by wave action, though the principal parts of ascending floors are at present sufficiently above the existing plane of the sea. Thus in Pl. LXII we see an example of the cases of chasms which are evidently due to wave action, but which have parts of their beds now much above the water level. Furthermore, it appears evident at various points on the shore, as is exhibited in Fig. 45 and Pl. LXI that the rock surface has been swept by waves when the sea had access to somewhat higher points than it has at present.

At first sight I was disposed to attribute this difference in the action of the waves to the gradual shoaling of the water of the coast and the consequent failure of the waves to attain the shore when they were operating with their utmost energy. A careful consideration of the facts, however, has satisfied me that this is not a sufficient explanation of the phenomena, for the reason that the evidence of uprising is conspicuous even on those parts of the shore where in the heaviest storms the waves do not break until they touch the shore line. Thus in the case of the excavated dike on the east side of Gloucester harbor, shown in Pl. LXII, the waves never have any great energy and yet they have clearly operated to excavate the dike to a height of about ten feet above the level at which they at present operate.

Passing upwards, we find the next level on which marine action is indicated at a height of about forty feet above the present high tide and thence upward to the height of about seventy feet. The operation of the sea at this height is more or less plainly shown around the whole of the periphery of Cape Ann, wherever the surfaces are well fitted to retain indications of marine action. Thus in Fig. 45, on the east shore of Gloucester harbor we note a portion of an extensive field which has been thoroughly washed by wave action and the crannies cleared of all save a few tightly wedged bowlders and the lines of weakness to a certain extent developed in the form of sea caves and clefts.

The next level exhibiting distinct marine erosion is at the height of from about one hundred to one hundred and thirty feet. The indications of marine action at this height are more distinct upon the eastern and southern portions of the island than upon other parts, for the reason that the rocks stand in more favorable positions for the exposition of such action and they are less thickly covered by a drift coating which might, as before suggested, conceal the effects of the waves. Above the height of 130 feet nearly the whole of the island is thickly covered with the morainal matter. The extreme instability of the slopes cut in this material is well shown by the constant movement of the detritus where it is exposed at steep slopes in existing railway cuts. A few thousand years of exposure, especially if the surface becomes subjected to the action of strong roots and the overturning of trees, would clearly serve to efface marine scarfs or other evidences of shore-line action.

The very fact that morainal drift on this island is mainly limited



VIEW NEAR BASS ROCKS—SALT ISLAND, MILK ISLAND, AND THATCHER'S ISLAND IN THE DISTANCE—SHOWING GENERAL CHARACTER OF SURFACE; HALF BARE ROCK, HALF TILL.

to heights above 100 feet is of itself evidence of a certain value to show the action of the sea. (See Pl. LXXV.) There is no other way in which we can so well account for the limitation in distribution of this drift as by the supposition that it has been worn away at lower levels by marine action, taking effect in the form of waves or of shore ice.

Below the general surface of rocks apparently wave swept, between the present level of the sea and the height of 140 feet, we almost invariably find a gently inclined talus, composed of materials which, we may presume, have been swept from the bared surfaces. Wherever we are enabled to get any section of this detrital matter it appears to be rudely stratified, much as the waste which has lately been stripped from the shore line is laid down at the foot of the sea cliffs.

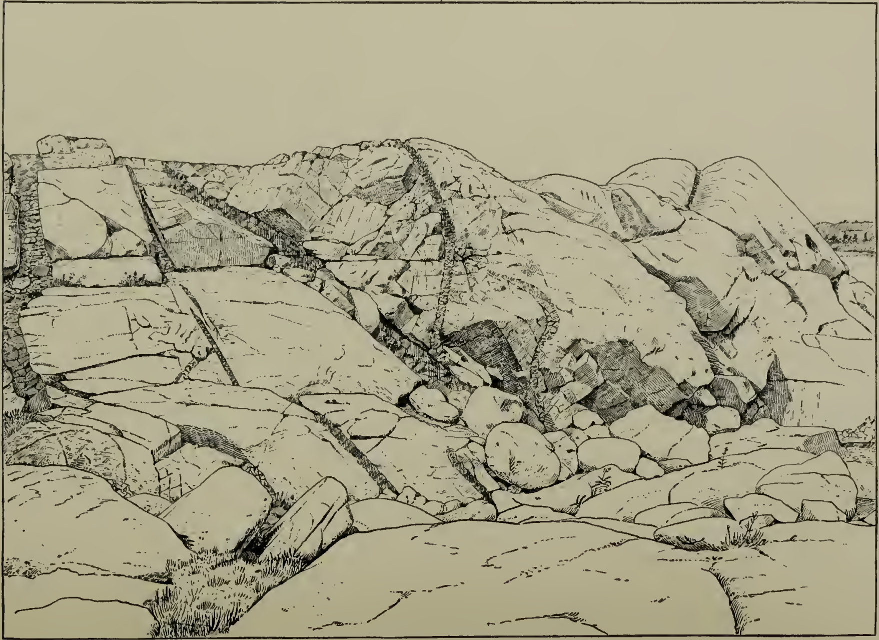
At first sight the observer may be surprised to find that these taluses have not their upper edge at a regular height above the level of the sea; in other words, they are not beaches formed at the foot of cliffs but under-water taluses, having only a partial likeness to the beach structures. If he will observe the existing shore line with the plummet to determine the depth of the taluses below sea water he will find that they exhibit an irregularity like that which we find at higher levels where we have assumed that the sea operated.

The only difficulty which we encounter in supposing that the phenomena in question are to be explained by marine action at higher levels is due to the fact that we fail to find distinct beaches of characteristic shape lying in positions corresponding to those they now occupy at lower levels. So far I have been unable to trace any unquestionable beaches which were formed during the time when the sea should have occupied the higher levels where I am disposed to believe it has been. The failure to find these structures is certainly an argument against a long continued action of the sea at any point above its present height. A careful study, however, has convinced me that beaches are not quickly or rapidly formed by marine action, but they represent the slow operation of forces which can come into action only under peculiar circumstances. Replacing the sea along this shore at the height of 100 feet in imagination, we note that the considerable depth of water of that shore line would make it impossible for the waves to come into possession of any large amount of detritus. The fine matter in moraines is relatively small in quantity, and the large bowlders are hard to move in the manner necessary to form beaches. All save the largest of them would quickly be dragged into the troughs of the shore, but it would evidently require a considerable time for the formation of any distinct beaches in the reentrants. At present a greater part of the pebbles which are found on such beaches are brought in by the action of marine plants, which, presumably, did not exist along this shore in the closing stages of the ice time. The sands of the sand beaches are heaved in from the seaward, owing to the fact that the water in the existing condition of the levels is tolerably shallow. With 100 feet added to the depth, they would be as completely wanting as they now are on many parts of the coast of Maine. It is only the beaches composed of large rounded pebbles, exceeding six inches in diameter, which we could expect to find along the shore line when it was at higher levels, and such accumulations never have the characteristic form of ordinary beaches.

There are many points about Boston where artificial scarfs such as those made by roads have been formed on slopes of drift materials and allowed by the abandonment of the way to return to a state of nature. Studying such localities, we observe that the action of frost and rain serves in the course of a score or two of years to destroy most of the superficial indications of such an excavation. Even after twenty years, in the case of scarfs which have been exposed in a steep wall three or four feet high, the effect of the cutting is very faintly indicated. It is impossible that such indentations would survive the processes of nature for as much as a thousand years on an ordinary surface. It is a noteworthy fact that on Mount Desert, where as noted in my report (loc. cit.) the old sea levels though distinctly indicated by excavations in the jointed granitic rocks, are rarely manifested in the detrital materials, only at altitudes within 100 feet of the sea level and in places where the detrital materials are more abundant than at any point on Cape Ann, do we find the marine action manifested in the form of beaches. Thus, on the periphery of Mount Desert, which has an extent of from 50 to 60 miles, there are but two places in all the ancient shore lines, having together a length of less than half a mile, where it is possible to determine the existence of sea-worn gravels disposed in their characteristic form. So it is hardly a matter of surprise that we should fail to find them on the much smaller area of Cape Ann, where the detrital matter is less suited to form beaches. Therefore, in endeavoring to ascertain the former presence of the sea at higher levels, I have relied upon the evidences of the scouring action of the waves and the indentations which they have produced on the bed rocks rather than upon the action exhibited by detrital materials.

DUNES OF CAPE ANN DISTRICT.

We may here note certain interesting features connected with the dune deposits which occur in the Cape Ann district. This portion of the shore of New England is interesting for the reason that it is one of the northernmost points at which extensive duning occurs, it being part of a field occupied by deposits of this nature extending from the northern point of Cape Ann to Portsmouth, N. H. (See Pl. LXIII). On the island of Cape Ann the most important dunes occur on the north shore and upon the east face of the island near



DIKES CUTTING HORNBLENDIC GRANITITE; BASS ROCKS.

Long Beach. Those near Long Beach belong to the ordinary category of shore dunes, which are in the process of growth at the present time.

On the north shore of that island we have a series of these dune deposits extending from near Halibut Point to Annisquam harbor, which are particularly interesting for the reason that they are evidently due to some conditions which are not in operation at present. All these dunes on the northern face of the island have long been grassed, and there is no indication that sand is now coming ashore in sufficient quantities to produce deposits of this nature. The water of the north shore is so deep that only very small amounts of sandy matter are from time to time scoured up among the rocks, yet it is evident that in a recent period the amount of sand yielded to the wind was large. The only way in which I can explain this peculiar feature is by supposing that at a time before the last subsidence, indicated by the submerged forest before described, this north shore was sufficiently elevated to afford sand beaches along the coast from which these dune sands have been swept inland.

In passing I may remark that the singular occurrence of what appear to be dune sands at various points remote from the present coast in Massachusetts and Rhode Island may perhaps be explained by the former presence of the sea at higher levels along the shore. On the mainland opposite Annisquam village, the point known as Coffin's Beach, there are very extensive dune deposits which are in the process of active construction. There is a tradition to the effect that two small farms which were tilled during the last century have been overwhelmed by the southern march of these sands. The genesis of these dunes is easily to be understood. The shore from Coffin's Beach to Newburyport trends in a general northwest direction, the whole of this coast constituting a great pocket beach on which the sands tend to move southwardly under the influence of the waves, their further southward journey being hindered by the salient of Cape Ann. The wind frequently blows in dry periods from the northwest and sweeps the beach sands southward to the bottom of the recess and accumulates them in these dune hills. It is likely that the southward movement of these sands was greater in the period of elevation just referred to than it is at present. Despite the evidence of the tradition which goes to show that these sands have recently advanced to the south, I am of the opinion that the accumulation of the deposit mostly took place in ancient times.

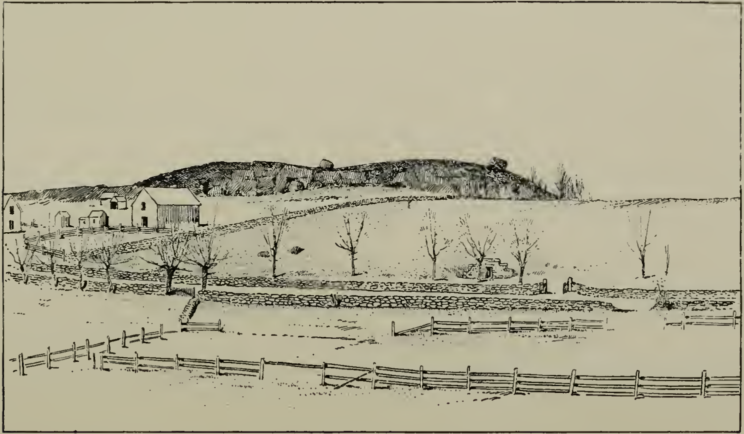
MARSHES.

The marshes of Cape Ann occupy but a limited area. They are divisible into three groups, fresh water deposits of the uplands, fresh water deposits formed behind walled beaches, and true tidal marshes. The upland morasses are all of small area and with the exception of a few deposits made in kame pits they lie altogether in irregularities of the ground or frontal moraines or in the numerous rock basins which beset the surface of the island. None of these areas appear to be drainable and they are therefore of no economic importance. The marshes impounded by beach walls are also of small extent, only one being of sufficient area for discussion. These lie on the shore between Briar's Neck and Bass Rocks. There is here an area of one hundred acres or more, the drainage of which is affected by the access of the tide and a portion of the field is ordinary salt marsh. By closing out the salt water by dams, with considerable exits for the inland waters, an important area can be reclaimed at this point. On Squam River, a considerable fiord which separates the island of Cape Ann from the main, there is a total area of about one hundred acres of reclaimable salt marsh. Unfortunately, a large part of this area is of a sandy nature. The sands which have worked down the shore from the northwest and which have formed in part the dunes of Coffin's Beach have poured into this basin and affected the character of the marshes as far south as Pearce's Island. Nevertheless, these marshes appear to me to be worth winning to agriculture. They can be reclaimed by very slight dams, for the reason that the waves they would face are of trifling size. Although the sand which has been contributed to these marshes will somewhat diminish their fertility, the admixture will make it easier for them to be reduced to the tillage state. Including the marshes along Little River, it appears to me likely that from 300 to 600 acres of high grade agricultural land can be won along the shores of this fiord.

PHYSICAL STRUCTURE OF THE BED ROCKS OF CAPE ANN.

One of the principal objects of this memoir is to set forth certain features connected with the crystalline rocks of Cape Ann. Nowhere along our coast are rocks of this description so well shown as here. With slight exceptions, where these materials are covered by recently formed beaches, the whole periphery of the island is exposed to view. These rocks form the root of a considerable anticline, the axis of which extends from northeast to southwest. The shore line of Cape Ann affords us by its varied outline extensive sections parallel with the trend of the anticline and across its axis. We are thus enabled to observe in a large way the nature of the accidents which took place during the movement which attended the formation of this mountain ridge.

This region is very favorably suited for the study of joint systems developed in the macro-crystalline rocks, and also for observations on a variety of dike injections which occurred at successive periods during the construction of the mountain uplift. At no other point on the east coast of the United States do we have anything like as good an opportunity to follow the dynamic history of the lower por-



PERCHED BOWLDER RESTING ON BARE GRANITE, ONE-HALF MILE NORTHWEST OF GLOUCESTER STATION; TAKEN FROM A POINT NEAR THE MAIN ROAD TO ANNISQUAM.

tion of an extensive anticline. In the interior districts of the country there are many points at which erosion has in a measure disclosed the substructure of great mountain arches; but so far as is known to me there is no case in which this structure is not very much masked by accumulations of soil or rubbly material. At this point the action of the sea has given us a remarkably clear horizontal section many miles in extent.

The disclosure of this anticline which the sea has afforded extends somewhat beyond the limits of Cape Ann. It begins on the southwest at Lynn and extends along the shore through Swampscott, Marblehead, Beverly, Manchester, and Magnolia, to Cape Ann. Although it is intersected at Cape Ann by the fiord indentation of Annisquam Reach, it is essentially a part of the same geologic structure. It will therefore be necessary to extend our consideration to the shore of Massachusetts Bay as far west as Lynn. It will be particularly desirable to effect this extension for the reason that in the section southwest of Cape Ann we have the peripheral deposits of the anticline fairly well disclosed, and can see the relations of the granitites to the superjacent deposits, which belong in the anticlinal fold or lie upon the node between the up curve and down curve of the mountain arch.

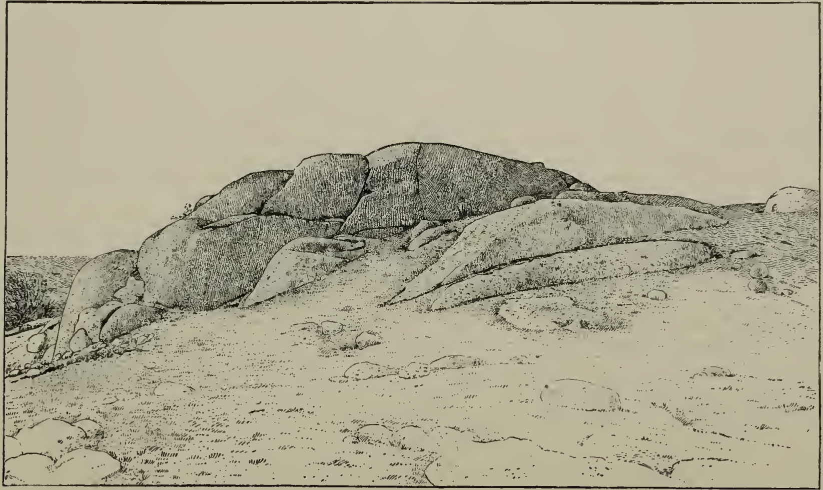
West of Lynn, in the region near the southwestern extremity of Boston Bay syncline, we have an extensive series of more or less metamorphosed rocks, including the Cambridge slates, the Roxbury conglomerates, the Nahant schists, and the Braintree fossiliferous slates. These beds have an aggregate thickness of not less than 6,000 feet, and they may be of much greater depth. They occupy the whole field of the central part of the syncline. In this section there have been very extensive though irregular extrusions of volcanic rocks, rocks which appear to have been in part at least the product of subaerial volcanic action. These deposits are found in the northern part of the syncline near Lynn, Saugus, and Malden. On the south shore they occur in Hingham and Nantasket. They apparently lie in immediate contact with the granitic series which compose the mass of the anticline, and were probably formed after these highly crystalline rocks took on their character and assumed their present relations to the mountain arch.

There can be little doubt that a large part of the beds which occupy the central portion of the syncline was deposited before the uplift of the anticlinal axis. The Braintree series appears to have been formed in deep water at a distance from the shore. The slates of Cambridge and Somerville which probably lie at the base of the Roxbury conglomerate also seem to have formed in deep water; but the Roxbury conglomerate contains abundant fragments among its pebbles which appear to have been derived from the erosion of the anticlines which bound the basin in which it lies. Not only are the granitites and their accompanying dikes of this anticlinal axis extensively represented, composing, indeed, in places a large part of the fragmental material, but the volcanic ejections before mentioned are also represented in these pebbles. It is also probable that a large part, if not the whole, of the Nahant series was deposited after the time when the syncline and the corresponding anticlines on the north and south had begun to develop.

Thus the general history of these mountain movements appears to have been as follows: Anterior to the orographic development of this district, it was occupied by an extensive series of deposits of unknown thickness and of early Cambrian age. Evidence which can not be given here appears to indicate that these ancient beds were considerably eroded before they were disturbed by mountain foldings; then came the formation of the anticlines, attended or followed by the volcanic outbreaks indicated by the remaining accumulations of this nature in Lynn and Nantasket districts. Afterwards, most likely in the period of the Potsdam sandstone, though perhaps at a subsequent date, came the extensive erosions from the anticlines and depositions in the syncline, which produced the Roxbury conglomerates.

This much of the history of the Boston axes is indicated by the beds which lie to the southwest of Swampscott. To the northeast of Swampscott, marine and other erosion has swept away or reduced below the ocean level all the beds which belong in the synclinal as well as those volcanic ejections which lie upon the flanks of the anticlinal, and thence outwardly to the extremity of Cape Ann we have only the roots of the old mountain axis which we are considering. From Lynn eastward the superficial deposits are almost entirely removed and exhibit the succession of crystalline rocks. At first on the west these are more or less gneissoid, and as we go east as far as Beverly they become more and more massive until we find the materials of the normal purely crystalline structure exhibited on Cape Ann. The section from Lynn to Annisquam Reach is in a general way beveled from the higher to the lower and more crystalline rocks. Although it is not possible to trace the section in detail, on account of the abundant faulting and other movements to which it has been subjected, I am inclined to think that there is a belt of gneissoid rocks, having a depth of from 1,000 to 3,000 feet, lying between the purely crystalline granites and the distinctly stratified Cambrian deposits of the syncline. In the main, the volcanic series appears to rest upon and break through these somewhat gneissic rocks.

From Lynn, where the massive crystalline rocks first come to the shore, eastward to Cape Ann, the coast line is abundantly intersected by dikes. Eastward as far as Marblehead, the larger part of these injections consist of distinctly porphyritic material. From Marblehead to Cape Ann, the proportion of this porphyritic material pro-



SUNSET ROCK, ANNISQUAM, MASSACHUSETTS, SHOWING HARD MASS ROUNDED BY GLACIATION AND STRIPPED OF ITS DEBRIS BY MARINE ACTION.

gressively diminishes and the dikes have an ordinary crystalline character becoming relatively more abundant. Along this part of the south wall of the anticline, in which the obscurely gneissic rocks find a place, the dikes are greatly disrupted. Thus, at the Preston House, near the line between the towns of Lynn and Swampscott, where there is a very extensive exposure of massive rocks that have been laid bare by the action of the sea, we find all the dikes extraordinarily ruptured by faults, and broken up in a degree never seen on Cape Ann. In general, it appears that the flanks of this anticline, in the section where the uplift of the anticline is turning to the downward flexure of the syncline, have been much more affected by disruptive movements than the central portions of the anticlinal axis which alone are represented on Cape Ann.

MINERALOGICAL CHARACTER OF ROCKS.

Within the limits of Cape Ann, saving in the case of small inclusions, all the granitic rock is of an entirely massive character. No trace of gneissoid structure has been observed in any part of that field, the fact probably being that the whole of the gneissic part of the section has been stripped away. Prolonging in a general manner the axis of such rocks as they appear on the southwest, it is readily seen that they come within a mile of the southern portion of this Cape.

Although the granites of Cape Ann vary somewhat in character in different parts of that field, at no point are the variations so far constant that any discrimination of the deposits into distinct areas, at least in the present state of our information, can be effected.

DIKES OF THE CAPE ANN DISTRICT.

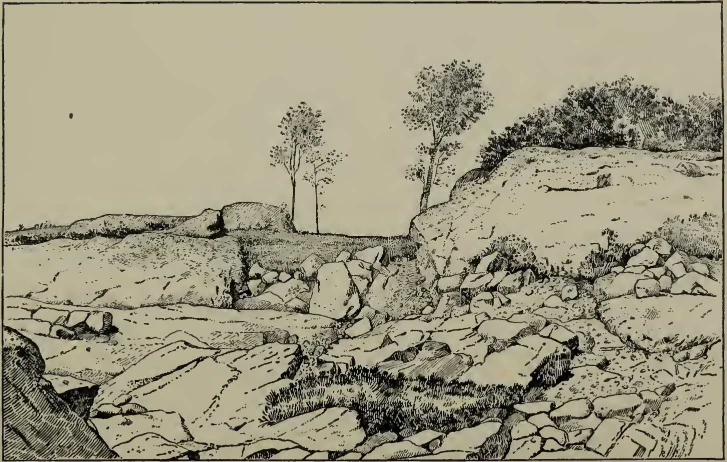
One of the aims of this inquiry has been to determine the number, character, and position of dike intrusions in this district. The study of the shore line where the rocks are bared by the sea, in quarries and other artificial cuttings, has shown a total of 361 dike intrusions. Some 30 dikes which have been observed only in quarries may be identical with some which appear on the coast line, but the repetitions are not likely to diminish the total as set forth above.

The portion of the crystalline rocks of Cape Ann which is bared by the action of the sea or by artificial openings probably does not exceed a twentieth of its total area. Although there are large surfaces of bed rocks exposed to view in the interior of the island, these areas in their natural state reveal few dikes, owing to the fact that the contents of these fissures readily decay and form crevices which are filled with rubble or drift materials. Only five dikes have been determined in these natural exposures of bed rocks, though many have been suspected to exist. The distribution of dikes on the shore, the abundant waste of such injections in the drift, and the other evidence before adduced go to show that these injections are about as numerous in the interior as they are on the coast. We may therefore reckon that the number of these intrusions within the limits of the island amounts to a much larger number than those exposed to view.

Neglecting at present the topographical character of the dikes, we find the general distribution of such fissures about as follows: Beginning with Eastern Point, we find that promontory moderately intersected with dikes to High Pebble Beach; from that point to Good Harbor Beach the number of these injections rapidly increases. At Bass Rocks they are about as abundant as at any point on the island, constituting perhaps a twenty-fifth of the visible mass. (See Pl. LIX.) They are also extremely abundant on Rocky Neck, in Gloucester harbor. From Bass Rocks to Cape Hedge the shore line is mainly occupied by beach accumulations. On the exposed portion of the shore occupied by Briar Neck inside of Salt Island the dikes are again extremely abundant. The indications derived from the interior appear to make it likely that the rocks to the west of Briar Neck are extensively cut by these injections, which mostly have a northwest and southwest extension. From Cape Hedge to Sandy Bay the number in a given extent of shore line diminishes; they are still, however, tolerably abundant. From Sandy Bay to Folly Cove they are substantially wanting, except in a small extent of shore on Halibut Point, where half a dozen occur. From Folly Cove southwestward they again become abundant and continue so to the mouth of Annisquam harbor, being most developed from Davis's Neck to the entrance of that harbor. Along the shore of Annisquam Reach from its northern mouth to Gloucester the conditions of the shore are not well suited to disclose these dikes, but the evidence seems to indicate that they abound in this portion of the section.

DISTRIBUTION OF DIKES.

The diagrammatic summaries showing the distribution of dikes give with close approximation to accuracy their distribution as regards compass directions. (Fig. 46.) It will be seen that of the 361 dikes the courses of which have been observed, including about all which are visible on the island, 266 lie in the quadrant between northwest and north, and 150 in the 25° between N. 45° W. and N. 20° W. It is thus evident that by far the greater part of the dikes, 266 out of 361, as against 95 in other parts of the circle, lie in the northwest quadrant, and more than half the total in the 45 degrees between north and northwest. The remainder of the dikes are irregularly distributed, the only considerable accumulation being in the portion of the circle between N. 30° E. and N. 60° E., where there are 44 dikes. The most remarkable concentration is that which occurs between N. 30° and N. 35° W., where in all there are 53 fis-



EAST SIDE OF GLOUCESTER HARBOR, SOUTHEAST FROM TEN-POUND ISLAND, SHOWING DIKE EXCAVATED BY SEA WHEN SHORE WAS ABOUT 10 FEET BELOW PRESENT LEVEL.

sures, or about a seventh of the total number. Thus the ratio of accumulation in these five degrees of the half circle is about as 7 to 36 in the remaining 175 degrees. As a whole the observed attitudes of these dikes show that they are far more developed in the quadrant from north to west than in the quadrant from north to east, in the ratio of 166 to 95, with, as before remarked, a singular concentration in the section between N. 30° W. and N. 35° W.

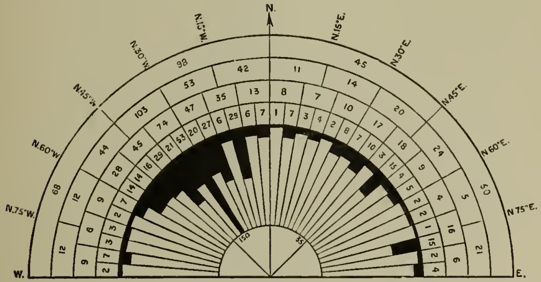


FIG. 45. Diagrammatic tabulation of strikes of dikes on the island of Cape Ann.

The appended diagram (Fig. 47) indicates the attitude of the dikes with reference to the vertical. It shows that the range in position is from 30° to 90°, with a steadfastly increasing number as we approach the vertical position. No dikes of any description have been seen in positions near a horizontal plane. No trace of anything like an approach to a laccolitic structure has been observed in any part of this field.

This enumeration does not include the large masses of diorite in the valley of the Annisquam Fiord nor the great masses of granite porphyry which lie in the same region and on the east shore of Cape Ann.

The range in diameter of the dikes is from a width of forty feet to very narrow intrusions with a width of half an inch, fine stringers often being not more than one-tenth of an inch in diameter at twenty feet from the main mass.

Owing to the conditions of exposure it has not proved possible to trace the horizontal extension of these injections. It is worthy of note, however, that in no case has it proved possible to find both ends of any injection, and in less than half a dozen cases has either extremity been seen. Considering the large number of dikes examined and the fact that many of them have been traced for hundreds of feet, it becomes clear that the longitudinal extension of these fissures is generally great. In the case of one dike, the great porphyritic intrusion of Pigeon Cove, there can be no question that it extends from a position one-fourth of a mile southwest of Straitsmouth Point, beneath Sandy Bay, to Pigeon Cove, and thence across the island to near Folly Cove. It is true that a portion of this extent is hidden by the sea, but such is the similarity in the physical character, general strike, and other features of the injection, that the identity of the dike throughout its length can hardly be doubted. The distance between these two points is about three miles.

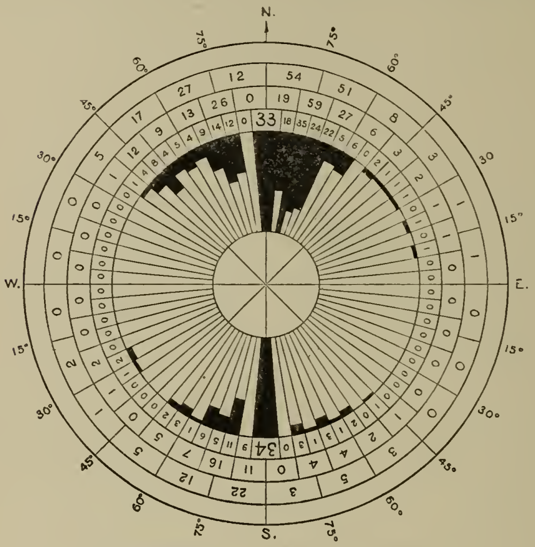
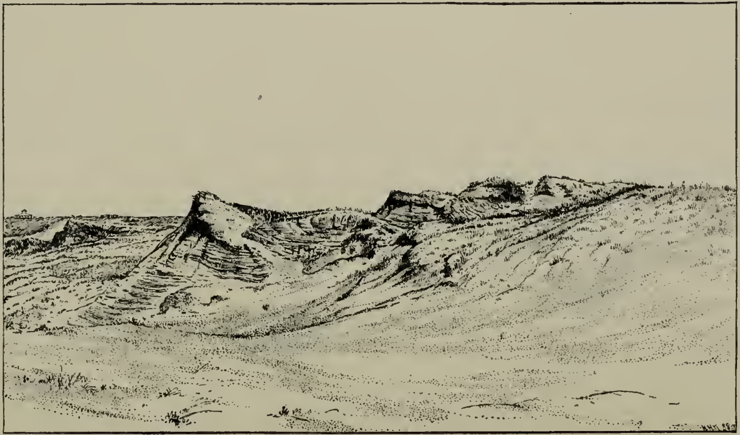


FIG. 46. Tabulation of dips of dikes on the island of Cape Ann.

These dikes in great part are characterized by clean walls, and as a whole they are not greatly cross-faulted, that is, the sides of the fissures are on the whole parallel, and there are few offsets. (See Pls. LXIV, LXV.) A certain group of quartz-porphyry dikes hereafter to be considered in detail have generally very irregular walls. In this case, however, there is no distinct indication of melting of the bounding walls, so that we can not perhaps regard the dikes as volcanic pipes, but must rather attribute the irregularity of their boundaries to some peculiar violence in the outbreak which produced them, or it may be that these ruptures were formed before the development of the joint planes. This latter conjecture is favored by the fact that these quartz porphyries are clearly the



SAND DUNES OF COFFIN'S BEACH.

oldest dikes in this section. Moreover, they are in a given field more faulted than the other dike systems, and therefore are shown to be of earlier age.

The faulting which has affected the district is principally indicated in the earliest set of dikes, viz., the quartz porphyries just mentioned. It is very slightly manifested in the case of the other fissures, and is indicated only at the points of intersection of different sets of dikes. It thus appears that the disruptive forces which produced the faulting did not, to any considerable extent, operate in this field after the work of intrusion was completed.

AREA OCCUPIED BY DIKES.

At this point we may notice an interesting theoretical consideration dependent upon the number of dikes in this region and the area which they occupy. Basing a computation, first, on a careful eye-estimate of the dike surfaces at different points, and, secondly, on an estimate of the number and diameter of the dikes, it appears pretty certain that on the surface of Cape Ann 5 to 10 per cent. of the superficial area is occupied by such materials. In other words, the horizontal extension of the granites has been increased by somewhere between one-tenth and one-twentieth of the original surface. Besides this increase, due to the injection of materials derived from below, the rocks have received a certain small though incomputable accession from vein materials, principally composed of quartz. In other districts this vein element is an important feature in the extension of the area. On Cape Ann it is so small that we may neglect it.

No particular order in the distribution of these veins has been observed. They are eminently abundant on Eastern Point, near Annisquam, and in the quarries about Rockport; they are rare elsewhere. They seldom exceed two or three inches in diameter and are generally of no considerable length. They do not appear to be connected with the faults, and are, therefore, probably in their nature secretions from the granitic mass formed during the cooling process.

I have elsewhere called attention to the fact that the injection of dike and vein stones would lead perhaps in part at least to movements of the strata which have resulted in the formation of anticlinal axes. It is interesting in this connection to note that a considerable extension of these basement deposits of the Gloucester anticline has taken place.

JOINT PLANES OF CAPE ANN DISTRICT.

The joint planes of the Cape Ann District as will be seen from the appended tables have been subjected to a careful study. I am not aware that in any preceding memoir involving a similarly extensive district the observations have been presented in an equally elaborate manner. The observations on these joint planes were made by a compass with a needle having a length of four inches, the circle graduated to degrees with a vernier attachment. In the course of the work, it quickly became evident that it was not possible on account of the decay of the rocks to observe joint phenomena in natural exposures with sufficient accuracy to obtain valuable results. The tabulated work, therefore, has been limited to quarries. It happens, however, that these artificial openings are so far distributed over the area of the island that they fairly represent the joint systems of the whole district. (See Figs. 48 and 49.) Inasmuch, however, as the general phenomena of joints along the coast are of great importance in determining the action of erosive forces, the detailed study of joint planes will be preceded by a general statement of their character on different parts of the coast, beginning as in the case of dikes with Eastern Point. Eastern Point as far as Brace's Cove exhibits much jointing, the principal fractures having an axis of N. 48° to N.

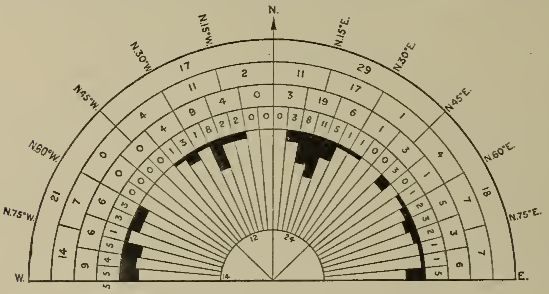


Fig. 47. Tabulation of joint planes in Bay View quarries.

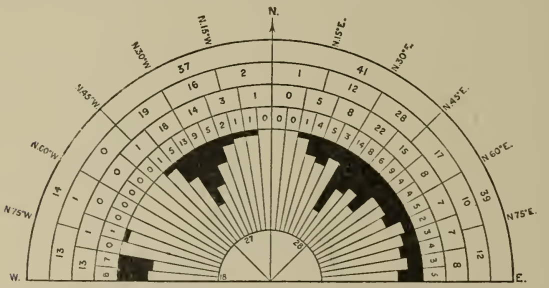
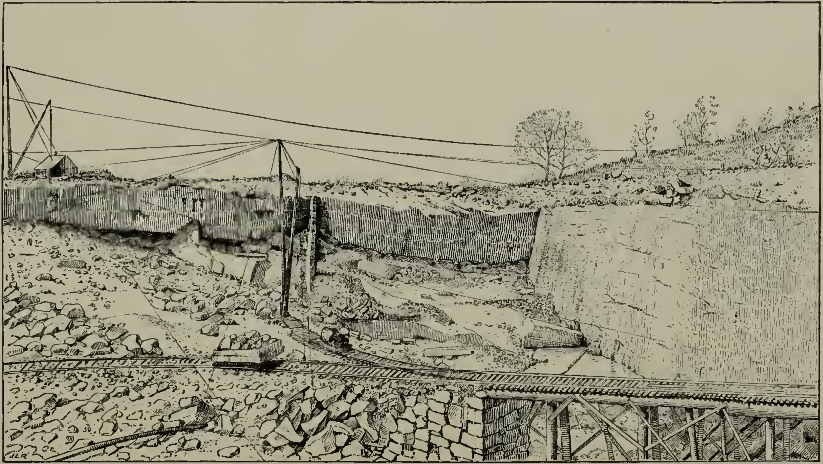


Fig. 48. Diagrammatic illustration of distribution of joint planes in Lanesville quarries.



PIGEON HILL QUARRY, UPPER PIT, SHOWING EXTREME DEVELOPMENT OF HORIZONTAL JOINTING.

53 ° E., dipping nearly vertically, a distance of eight feet apart, varying from one inch to 20 feet, and averaging three or four feet. There are other joints in the same region which can not clearly be referred to any system. Owing to the high angles of the principal joints, the weather and ice have not much affected the rocks in this portion of the section, and as a consequence it is one of the boldest portions of the shore of the island. In the vicinity of Brace's Cove the joint planes are close together, averaging less than a foot apart, and inclining in various directions, so that the rock splits in small fragments of little more than one-fiftieth of a cubic foot. It is probably to this morcellated character of the rock given by the joints that we owe the great erosion of the granites which has formed the low land in which lie Brace's Cove, Niles's Pond and the other depressions of this vicinity.

From Brace's Cove to Bass Rocks the manifest joint systems are fewer in number and the places farther apart. With this diminution in jointing, the shore again assumes a bold character. At Bass Rocks the joint structure is very imperfectly developed (Pl. LIX), the rocks being here perhas more massive than at any other point on the periphery of the island, although the dike injections are more numerous here than elsewhere. From Bass Rocks to Cape Hedge the joints are again more numerous, and to this greater development may perhaps be due the recession of the shore on this part of the island. At certain points the jointing in the measure of its development approaches the conditions shown at Brace's Cove. From Cape Hedge to Straitsmouth Point, there are but two distinct vertical systems of joints which are evident, viz. those running N. 48° W. and those running N. 32° E., together with a horizontal set, the three serving to detach numerous very massive fragments. At several points on this portion of the coast are small patches of granite which are almost as much jointed as the large field of such material at Brace's Cove. Wherever these patches occur the effect of marine erosion is at once evident. The coast line is beaten back until in process of retreat it obtains a certain protection from the assault of waves from detritus which lodges in the re-entrant angle. Going north from Eastern Point this is the first portion of the shore on which the horizontal jointing distinctly appears.

On the south shore of Sandy Bay, between Straitsmouth Point and the village, the vertical jointing runs N. 3° W. and N. 52° E. At this point the distinct horizontal joint planes become less marked and are replaced by a number of divergent planes. From Sandy Bay along the shore to Folly Cove, we have the conditions of jointing which are shown in detail in the Pigeon Cove quarries. (See Pls. LXVI, LXVII, LXVIII, LXIX, LXX, LXXI.) The planes strike N. 78° W. with a dip to the NE. of 55°. Another set of nearly horizontal shelving somewhat irregular joint planes strikes in a general way east and west, dipping to the south at an angle of 10° or 12°. Yet another set strikes N. 43° E. with a vertical dip. These three joints lead to the formation of rhomboidal fragments which are frequently as much as 4 feet wide, 12 feet long and varying from 1 to 4 feet in thickness. The size of these fragments shows that the joint planes are far apart. The attitude of the planes towards each other and their position in relation to marine erosion has doubtless served to protect this part of the island from glacial and other wearing, and has thus led to the preservation of the great salient which terminates in Halibut Point. So, too, the generally level character of this area and the gradual slope with which it meets the sea may be accounted for by the attitude of the joint systems. The joints of this section, particularly those which strike N. 43° E., are remarkable for the continuity of the individual planes. In some cases they may be observed extending on the shore line for the distance of 300 feet or more.

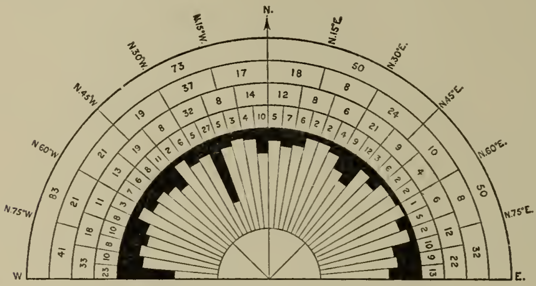


FIG. 49. Tabulation of joints in Rockport quarries.

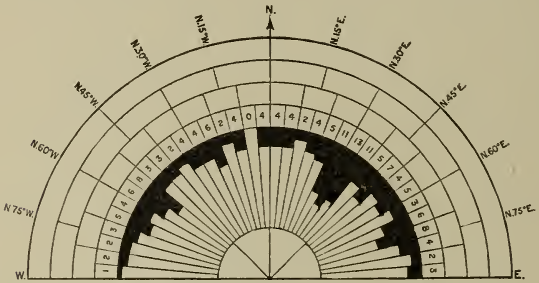
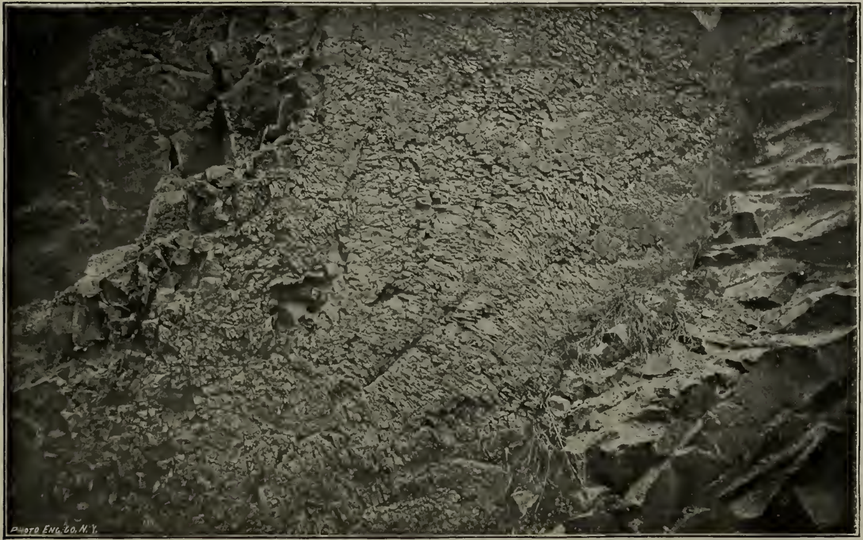


FIG. 50. Tabulation of joint planes in Pigeon Cove quarries.



BASALTIC JOINTING IN DIKE AT STONE BRIDGE ONE-QUARTER OF A MILE EAST OF GLOUCESTER.

The rock is less cut by joint planes and therefore more massive in the region about Andrews Point. At Halibut Point, the strong northeast waves have disrupted a large quantity of material which serves in a measure to protect the shore from the further assault of the waves. The vigor of the wave action is shown by the size of the fragments thrown up far beyond the ordinary range of the sea. Between Halibut Point and Folly Cove is a section of rock which has been subjected to interstitial decay and exposes the joint planes imperfectly. The depression of Folly Cove and the trough which extends southward for a mile or more from its head is perhaps caused by a lack of resistance in the material. Folly Point is characterized by a considerable immunity from jointing. These joints are at this point so irregular that it does not seem possible to reduce them to definite sets.

A moderate immunity from joints characterizes the whole shore from Folly Cove to Annisquam, and here also it has not proved possible to reduce the joint planes to a definite order.

The shores of Annisquam Reach exhibit a system of very closely juxtaposed joints which so divide the rock that it normally breaks up into fragments not exceeding about ten cubic inches in contents. It is perhaps to the ample jointing of this section that we owe the deep and continuous depression in which lies this system of fiord of Annisquam River. (See diagrams of jointing in quarries, Figs. 50, 51, 52, and Pls. LXXII, LXXIII, LXXIV.)

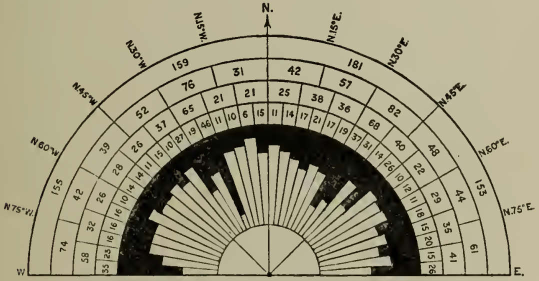


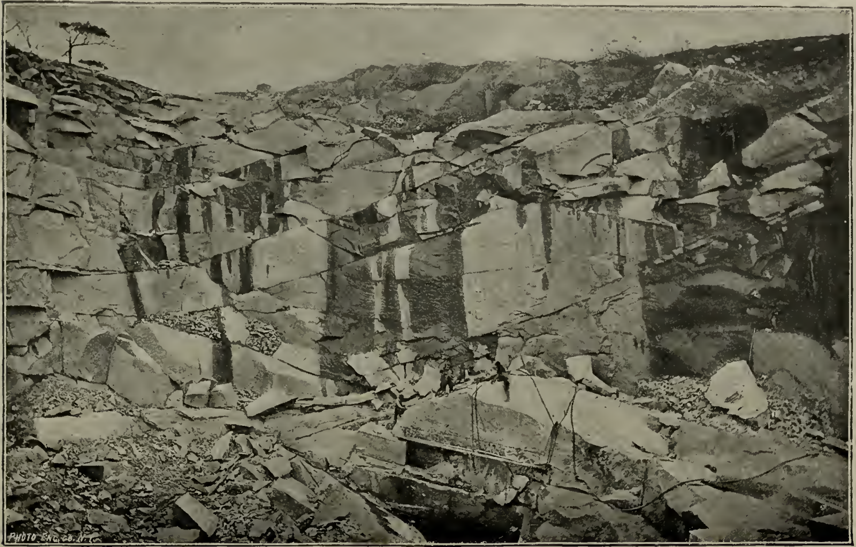
Fig. 51. General tabulation of joint planes.

The foregoing survey of the shore from the point of view of joint planes, makes it tolerably evident that there is some relation between the salients and re-entrants of the coast line and the jointed character of the rocks. A study of the field would show the student that this is the case more effectively than it is indicated to him by the necessarily cursory account which we have given him. In fact, the measure of resistance both to marine and glacial action, the two modes of erosive energy which have in the main shaped this region, is in good part determined by the attitude of the joint planes. The preceding pages afford a basis for this general description as far as the sea shore and wave action are concerned. Evidence of a similar sort may readily be found to show the influence of the joint planes on glacial wear. Thus whenever the granitic rocks form sharp projections in the interior district, we always find these salients to be composed of little jointed material, while in the depressions a variety of evidence freely leads to the inference that they are occupied by rocks more closely intersected by these rupture planes.

Turning now to the conditions in the several quarries, we note the following facts concerning joints in different parts of the field which have been bared by quarrying work. Fig. 50 exhibits the attitude of the joint planes in the Rockport system. It will be seen by the diagram that the joints having their planes in the northwest quadrant amount to 156, while those in the northeast quadrant amount to but 100; those in the north-northwest octant to 73, while those in the northwest-by-west octant amount to 83. Thus, as in the case of the dikes, though in a less degree, there is in this particular part of the field an accumulation of joints in the northwest quadrant.

In the Pigeon Cove quarries (see Fig. 51) the conditions are reversed. There are 53 joint planes in the northwest quadrant and 101 in the northeast quadrant. In the Lanesville quarries the conditions are like those at Pigeon Cove, with a proportionately greater number in the northeast quadrant, the numbers being 51 in the northwest quadrant and 80 in the northeast quadrant. In the Bay View quarries, there is very little difference between the number of joints in the two quarries, there being 38 in that of the northwest and 47 in the northeast quadrant.

Thus it appears as the result of sufficiently numerous observations of the joint planes and their associated dikes that while the dikes distinctly follow joint planes there does not appear to be any such relation between them as would enable us to say that the number of dikes was in any measure determined by the number of incipient fissures afforded by the joints, or, in other words, the conditions which guided the direction of the dikes were probably due to some feature or condition not inherent in the joints themselves.



ROCKPORT GRANITE COMPANY'S QUARRY, SHOWING ABSENCE OF VERTICAL JOINTS AND CHANGE IN CHARACTER OF PLANES IN THE DEEPER PARTS OF THE SECTION.

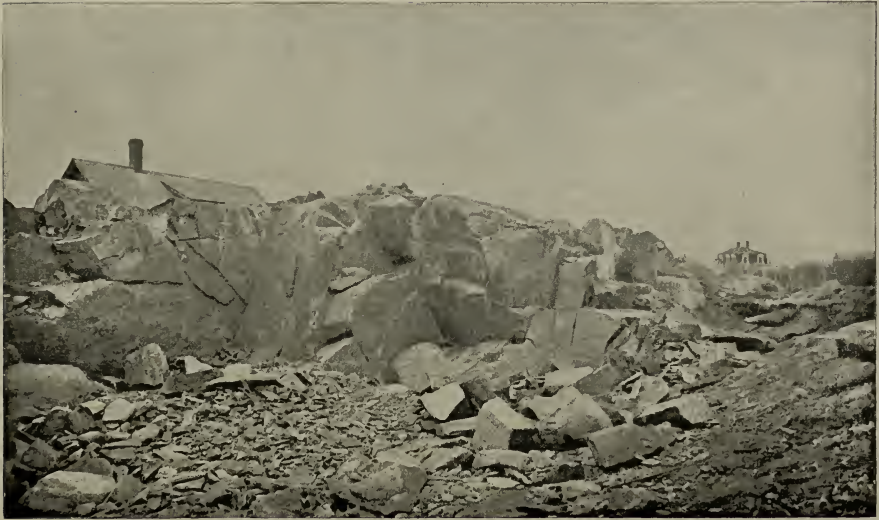
LIST OF DIKES OF CAPE ANN.

[The numbers in the following list refer to corresponding numbers upon the map of the bed rocks of Cape Ann. The identification of the dike rocks has been mainly from hand specimens and necessarily no attempt has been made to classify them upon strictly petrographical grounds.]

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
1	N. 17° E.	85° W.	2½ feet	Diabase	An irregular dike.
2	N. 77° E.	75° N.	2 feet	Porphyritic diabase	Somewhat faulted.
3	N. 2° E.	70° SE.	10 feet	Quartz porphyry	
4	N. 72° E.		2½ feet	Porphyritic diabase	
5	N. 12° E.	60° W.	12 feet	Diabase	
6	N. 77° E.	85° N	3 feet		Worn into a deep chasm for considerable distance above high tide.
7	N. 77° E.	60° N	1½ feet	Diabase	
8	N. 12° E.	75° W.	7 feet	Quartz porphyry	
9	N. 17° E.	90°	2½ feet	Porphyritic diabase	An irregular dike.
10	N. 3° W	75° N	8 feet	Quartz porphyry	
11	N. 13° W. to N. 22° E.	75° W.	11 feet	Diabase	Crystals of feldspar 6 inches long.
12	N. 27° E. to N. 13° W.			do	A chasm.
13	N. 58° to 81° W.	90°	3 to 6 feet		
14	N. 12° E.			Feldspar porphyry	
15	N. 83° W. to N. 57° E.	90°	3½ feet	do	A very irregular dike.
16	N. 21° to 42° E.	80° N	3 feet	Diabase	
17	N. 62° E.	80° N	4 feet	Porphyritic diabase	Very irregular. Cuts 16.
18	N. 53° W		8 inches	Diabase	
19	N. 47° E.	90°	3½ feet	do	
20	N. 67° E.		2 feet	do	
21	N. 52° E.	90°	2 feet		
22	N. 77° E.	75° N	3 feet	Diabase	
23	N. 62° E.	50° S.	½ inch to 4 feet.	Feldspar porphyry	Very irregular and ragged.
24	N. 42° E.	60° N	3½ feet	Diabase	
25	N. 47° E.		8 inches		
26	N. 32° E.	55° N	3 feet		
27	N. 22° to 42° E.	90°	2½ feet	Diabase	
28	N. 57° E.	75° N	3½ feet		
29	N. 13° W	80° N	7 feet	Diabase	A chasm.
30	N. 87° E.	80° N	15 to 18 feet	do	
31	N. 43° W	80° SW	6 feet		
32	N. 28° W	60° E.	2 feet	Diabase	
33	N. 33° W	90°	1½ feet		
34	N. 78° W	60° W.	2½ feet		
35	N. 83° W	70° N	18 feet	Diabase	Irregular.
36	N. 43° W	90°	3½ feet	do	
37	N. 27° E.	60° SE	2 feet		
38	N. 25° W	90°	1 foot	Diabase	
39	N. 38° W		6 feet		
40	N. 33° W		2 feet		
41	N. 38° W	70° SW	2 feet	Diabase	
42	N. 63° W	85° SW	3 feet	Porphyritic diabase	Very irregular.
43	N. 27° E.	60° NW	4 feet	do	
44	N. 33° W	80° SW	4 feet		

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General Remarks.
45	N. 13° W	80° SW	2 feet	Diabase	
46	N. 33° W to N. 37° E.	55° SW	1 foot		Very irregular.
47	N. 42° E.	70° NW	6 inches		
48	N. 13° W	60° NE	3 feet		Rather irregular.
49	N. 77° E.	70° S.	3 feet		
50	N. 43° W		6 to 8 inches		Very irregular.
51	N. 53° W	90°.	2½ feet		
52	N. 37° E.	70° SW	5 feet	Feldspar porphyry	
53	N. 49° W	90°	1½ feet	do	
54	N. 37° E.	70° NW	4 feet	Diabase	
55	N. 58° W	90°	22 feet	Feldspar porphyry	Cut by 57 and probably by 56.
56	N. 47° E.	50° NW	10 feet+		
57	N. 47° E.	75° N	7 feet	Diabase	
58	N. 58° W	70 to 80° NE	20 feet		
59	N. 62° E.	75° W	3 feet	Diabase	
60	N. 52° E.	80° N	2½ feet	do	
61	N. 49° E.	90°	4 feet	do	
62	N. 77° E.	75° N	4 feet	do	
63	N. 47° E.	75° N	3 feet+	do	
64	N. 27° E.			do	A chasm with the dike matter washed out.
65	N. 58° W	90°.	3 to 4 feet	do	Very irregular.
66	N. 1° W	35° W	4 inches	do	Disappears.
67	N. 52° E.	65 to 70° N.	2½ inches	do	
68	N. 41° W	90°	1 foot	do	
69	N. 38° W	90°	4½ feet	do	
70	N. 77° E.	75°	6½ feet	Feldspar porphyry	
71	N. 13° W.	90°	4 to 5 feet	Diabase	
72	N. 33° W	90°	9 feet	do	
73	N. 7° E.	90°		do	73 cuts 70.
74	N. 53° W	83° S.	1½ inches	do	Disappears.
75	N. 43° W	75° S.	1½ to 2½ inches.	do	
76	N. 53° W	80° S	3½ feet	do	
77	N. 59° W	90°	3½ feet	do	
78	N. 33° W	80° NE.	3½ feet	do	78 branches forming 78ᵃ.
78ᵃ	N. 18° W	75° E.	3½ feet	do	
79	N. 18° to 33° W.	90°	4 feet +		Dike matter eroded away.
80	N. 63° W	90°.	7 feet	Diabase	
81	N. 33° W	75° W		do	
82	N. 61° W	90°	1 foot	do	
83	N. 35° W	80° E.	6 feet		
84	N. 30° E.	70° N (?)	10 feet (?)	Diabase (?)	
85	N. 51° W		6 feet +	Diabase	
86	N. 49° E.	70° S.	5 inches to 1 foot.	do	
87	N. 43° W	80° E.	4 feet		
88	N. 49° W	80° +		Diabase	
89	N. 57° E	75° S.	2 to 3 feet	do	
90	N. 23° W		6 feet	do	
91	N. 47° E.		8 feet	do	
92	N. 27° E	45° N	3½ feet	Feldspar porphyry	
93	N. 23° W	80 to 85° E.	3 feet	Diabase	



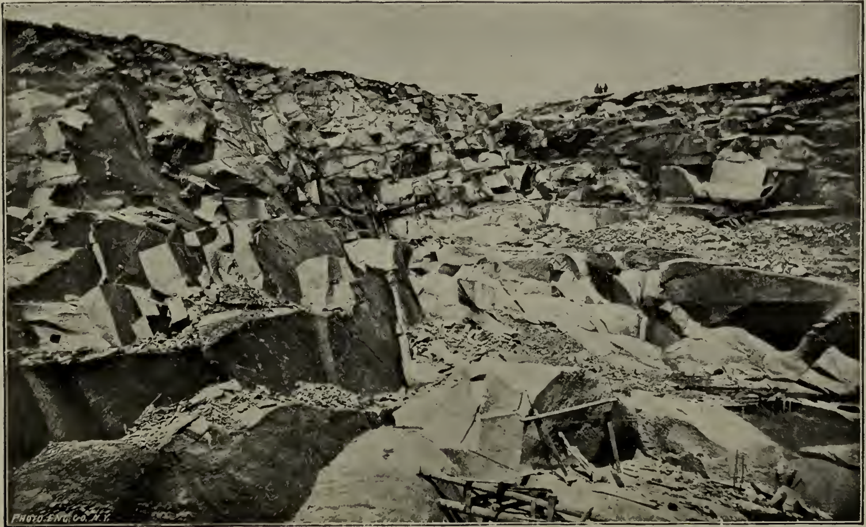
DORMAN'S QUARRY, ON SIDE OF MAIN ROAD FROM ROCKPORT TO PIGEON COVE, SHOWING TWO PRINCIPAL SETS OF JOINTS.

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General Remarks
94	N. 63° W	90°	21 feet	Diabase	
95	N. 87° E.	90°	1½ feet	do	
96	N. 47° E.	80° N	1½ feet	do	
97	N. 6° E	80° SE	1½ feet		
98	N. 43° W.		5 feet		
99	N. 53° W	80° NE			Irregular.
100	N. 47° E.	75° N	½ inch		
100ᵃ	N. 17° E.	75° NW	1 inch		
100ᵇ	N. 37° E.	75° N	2½ inches		
101	N. 48° W		1 foot		
102	N. 37° E.	75° N	1½ feet	Diabase	
103	N. 13° W	70° E.	1 foot		
104	N. 58° W		15 feet +	Holocrystalline diabase.	
105	N. 43° W. to N. 57° E.	70° S	6 inches to 1½ feet.	Diabase	Very irregular.
106	N. 13° W	70° E	1½ feet	do	
107	N. 37° E.	90°	3 feet	do	
108	N. 9° W	70° E	12 feet	do	
109	N. 33° W	82° W	3 feet	do	Probably an offshoot of 108.
110	N. 38° W	90°	3 feet	do	
111	N. 23° W	90°	5 to 6 inches	do	
112	N. 23° W	75° E	4 inches		
113	N. 33° W		3 feet	Feldspar porphyry	Forked dike.
113ᵃ	N. 58° W	50° NE	2½ feet	do	do.
113ᵇ	N. 43° W	65 to 85° NE	2 feet	do	do.
114	N. 35° W	80° E	2½ feet		
115	N. 23° W	75° E	9 feet		
116	N. 33° W	15° E	1 foot	Quartz porphyry	Very irregular.
117	N. 23° W	85° E	2½ feet	Diabase	
118	N. 27° E.	50° NW	8 inches	do	do.
119	N. 17° E.	45° W	1½ feet	do	Forked dike.
119ᵃ	N. 17° E.	45° W	1 foot	do	do.
119ᵇ	N. 32° E.	45° W	1 foot	do	do.
120	N. 57° E.	50° NW	2 feet	do	Cuts 121.
121	N. 33° W	90°	10 feet	do	Extremely irregular and faulted.
121ᵃ	N. 43° W	90°	10 feet	do	do.
121ᵇ	N. 13° W	70° E	2 feet	do	do.
121ᶜ	N. 43° W	90°	2 feet	do	do.
122	N. 38° W	60° E	1 foot	do	
123	N. 28° W	80 to 85° NE	6½ feet	do	Forked dike.
123ᵃ	N. 35° W	85° NE	6½ feet	do	do.
123ᵇ	N. 43° W	80° NE	2 feet	do	Offshoot of 123.
124	N. 33° W	90°	9 feet	Porphyritic diabase	
125	N. 43° W	90°	1 foot		
126	N. 67° E.	70° S	2 feet	Diabase	
126ᵃ	N. 77° E.	65° S.	6 inches	do	
126ᵇ	N. 73° W	70° S.	1 foot	do	
126ᶜ	N 12° E	60° S	1 foot	do	
127	N. 37° E.	60° N	10 feet	Quartz porphyry	
128				do	Very ragged and irregular.
129	N. 77° E.		15 feet	do	Irregular.
130	N. 18° W	80° E	10 feet	Diabase	
131	N. 33° W	80° SE	2 feet	do	

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
132	N. 53° to 63° W.		2 feet	Diabase	
133	N. 47° E.	40° N.	8 inches	do	
134	N. 27° to 57° E.	50° N.	2 feet	do	
135	N. 47° E.	65° N.	50 to 60 feet	Quartz porphyry	Very irregular and ragged
136	N. 83° W.	45° N.	3¼ feet	Diabase	
137				Quartz porphyry	Ragged and irregular.
138	N. 21° W.	75° NE.	2 feet	Diabase	Irregular.
139	N. 3° W.	80° NW.	2 feet	do	
140	N. 13° W.	76° NW.	3 feet	do	
141	N. 5° E. to 13° W.		8 feet	do	
142	N. 32° E.		10 feet +		
143	N. 18° W.	90°	1 foot		
144	N. 32° E.	45° NW.	7 feet	Diabase	
145	N. 32° to 67° E.	55° NW.	6 feet		
146	N. 67° E.	80° N.			
147	N. 53° W.		2¼ feet	Spherulitic quartz porphyry.	
148	N. 13° W.		2 feet		
149	N. 3° W.	90°	2 feet		
150	N. 83° W.	80° N.	5 feet	Diabase	
151	N. 48° W.	85° S.	9 feet	do	
152	N. 47° W.	85° S.	9 feet	do	
153	N. 52° E.		2 feet	do	Irregular.
154	N. 47° E.	55° N.		do	Cut by 157.
155	N. 32° E.	60° N.	6 feet	do	Irregular.
156	N. 33° W.	90°	2¼ feet	do	
156a	N. 33° W.	65° E.	1 foot	do	
157	N. 47° E.	90°	2 feet	do	
158	N. 13° W.	90°	1½ feet	Feldspar porphyry	
159	N. 23° W.	80° NE.	8 feet	do	Irregular.
160	N. 47° E.	60° NW.	20 feet +		
161	N. 23° W.	80° NE.	7 feet		
162	N. 13° W.	90°	2 feet	Nelaphyric diabase	
163	N. 31° W.		10 feet +	Diabase	
164	N. 30° W.	80° NE.	3½ feet	do	
165	N. 7° E.	50° W.	4½ feet	do	Irregular.
166	N. 13° W.	90°	3 feet	do	
167	N. 41° W.	75° E.	12½ feet	do	
168	N. 37° W.	68° SW.	1 foot	do	
169	N. 25° W.	75° NE.	4 feet		
170	N. 13° W.	35° NE.	1½ to 2½ feet	Diabase	
171	N. 7° E.	50° NE.	1 foot	do	
172	N. 9° W.	80° NE.	18 feet	do	
173	N. 23° W.	80° NE.	3 to 3½ feet.	Porphyritic diabase	
174	N. 32° E.	55° N.	3 feet	Diabase	
175	N. 21° W.	80° NE.	18 feet	Porphyritic diabase	Same as 172.
176	N. 37° W.	30° S.	1 foot	Quartz porphyry	
177	N. 77° E.	75° N.	18 feet	Diabase	
178	N. 73° E.	75° N.	21 feet	do	
179	N. 83° W.	70° N.	1 foot 5 inches.	do	
180	N. 78° W.	80° N.	2¼ feet	do	
181	N. 87° E.	80° N.	3 inches	do	
182	N. 73° W.	65° W.	3½ feet	Feldspar porphyry	



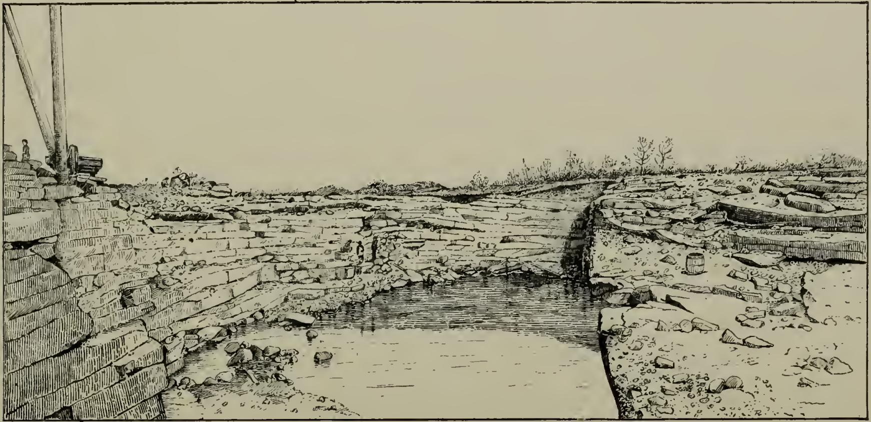
ROCKPORT GRANITE COMPANY'S QUARRY NORTHERN END OF LOWER PIT, SHOWING PROGRESSIVE INFREQUENCY OF JOINTS AT DEPTHS BELOW THE SURFACE.

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
183	N 41° W	70° NE	5 feet	Feldspar porphyry	Irregular.
183^{a}	N. 87° E.	80° NE	3 feet	do	
184	N. 43° W	85° NE	1 foot 5 inches.	do	Offshoot of 183.
184^{a}	N. 45° W		4 feet	do	
185	N. 27° E.	65° W.	3½ feet	Diabase	
185^{a}	N. 77° E.	80° N	16 feet	do	
186	N. 7° E	70° N	25 to 35 feet		
187	N. 2° E.	70 to 80° W.	3 feet	Altered porphyritic diabase.	Chasm.
188	N. 77° E.		3 feet	Diabase	
189	N. 53° W	75° S	2 feet		Irregular.
190	N. 43° W	80° NE			
191	N 43° W	80° E	8 feet	Diabase	
192	N. 53° W				
193	N. 27° E	55° N	4 feet	Diabase	Chasm.
194	N. 53° W	90°.	5 feet	do	
195	N. 38° W	85° E	10 feet	do	
196	N. 42° E		30 feet	Altered porphyritic diabase.	Same as 187 (?) Irregular.
197	N. 83° W		20 feet	Diabase	
198	N. 32° E.	70° N	14 feet	do	
199	N. 47° E.		½ inch to 1½ feet.		
200	N. 53° W		3 feet	Diabase	Irregular.
201	N. 47° E.			Altered diabase	
202	N. 57° E.	70° N	10 feet	Diabase	
203	N. 77° E.	70° N	5½ feet	do	
204	N. 37° E	45° N	2½ feet	do	Disappears.
205	N. 82° E.	80° N	22 feet	do	
206	N. 58° W	75° W	2 feet	do	
207	N. 58° W	90°	2½ feet		
208	N. 78° W	75° N	2½ feet	Feldspar porphyry	
208^{a}	N. 28° W	65° NE	6 feet	do	
208^{b}	N. 28° W	80° NE	12 feet	do	
209	N. 47° W	75° NE	2 feet	Diabase	
210	N. 29° W	75° NE	4 feet	do	
210^{a}	N. 38° W	80° NE	3 feet	do	
210^{b}	N. 33° W	75° NE	3 feet	do	
211	N. 43° W	80° NE	3 feet		
211^{a}	N. 43° W	80° NE	1½ feet		
212	N. 33° W	80° NE	18 to 20 feet	Very augitic diabase	
213	N. 38° W		3 to 4 feet		
214	N. 37° E.			Feldspar porphyry	Very irregular.
215	N. 23° W	80 to 85° E.	15 feet	Diabase	
216	N. 48° W		3 feet	do	
217	N. 77° E.	70° N	4 feet	do	
218	N. 28° W	90°	9 feet	do	
219	N. 77° E.	50° N	1½ feet	Diorite (?)	
220	N. 33° W	85° E	1 foot		
221	N. 13° W		1½ feet	Diabase	
222	N. 77° E.				
223	N. 58° W	80 to 85° NE	3 feet		
224	N. 38° W	85° NE	1½ feet		

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
225	N. 33° W		2 feet		
226	N. 50° W	90°	9 feet		
227	N. 43° W	50° NE	10 feet	Quartz porphyry	
228	N. 33° W	90°	3 feet	Diabase	A bow-shaped dike.
228^{a}	N. 83° E.	90°	3 feet	do	do.
229	N. 33° W	90°	3 feet	do	
230	N. 37° W	80° W	30 feet		
231	N. 13° W		5 to 10 feet.	Diabase	
232	N. 39° W	80° NE	3 feet	do	
233	N. 31° W	90°	2½ feet	Feldspar porphyry	
234	N. 13° W			Diabase	Very irregular.
235	N. 31° W	80° NE	9 feet	Feldspar porphyry	
236	N. 23° W	85° NE	1¼ feet	Diabase	
237	N. 37° E.			Diorite porphyrite.	
238	N. 33° W		1½ feet	Diabase	
239	N. 13° W	90°	3 feet		
240	N. 13° W	90°	3 feet		Cut by 241 and 241^{a}.
241	N. 73° W	75° N	9 feet	Diabase	Irregular and very much branched.
241^{a}	N. 88° W	75° N	5 feet	do	do.
241^{b}	N. 58° W		¾ inch	do	do.
241^{c}	N. 58° W		5 inches	do	do.
241^{d}	N. 58° W		½ to 5 inches	do	do.
241^{e}	N. 13° W		8 inches.	do	
241^{f}	N. 13° W		5 inches	do	
242	N. 33° W	70° NE	12 feet	do	
243	N. 33° W	90°	: ½ feet	Porphyritic diabase	
244	N. 37° W	70° NE	4 to 5 inches	Diabase	Irregular.
245	N. 33° W	80° NE	1¾ feet	Quartz porphyry	
246	N. 28° W	80° NE	21 feet	Diabase (?)	
247	N. 33° W	80° SW	2½ feet		
247^{a}	N. 33° W	80° SW	2 feet		
247^{b}	N. 43° to 63° W.		2 feet		
247^{c}	N. 33° to 68° W.				Joining 247^{d}.
247^{d}	N. 33° W	80° SW	3 feet		
248	N. 43° W		½ to 2 feet.	Diabase	
249	N. 38° W	90°	3 feet	do	
250	N. 43° W	75 to 80° SW.	4 feet		
251	N. 48° W	80° S	3 inches		
252	N. 37° W	80° SW	3 to 4 feet.	Diabase	
252^{a}	N. 23° W	85° SW	15 inches		
253	N. 33° W	90°	1 foot		
254	N. 48° W	80° SW	3 feet 3 inches.	Diabase	
255	N. 33° W	90°	10 feet	do	
256	N. 53° W	88° S	4 feet	do (?)	
257	N. 13° W	25° E	3½ feet	do	
258	N. 35° W	75° E	15 feet +	do	
259	N. 37° W	75° NE	3½ feet	do	
260	N. 45° W	90°	3 feet		
261	N. 25° W	70° NE	3 feet		
262	N. 38° W		15 feet +		
263	N. 29° W		2 feet		
264	N. 33° W		10 feet +	Diabase	



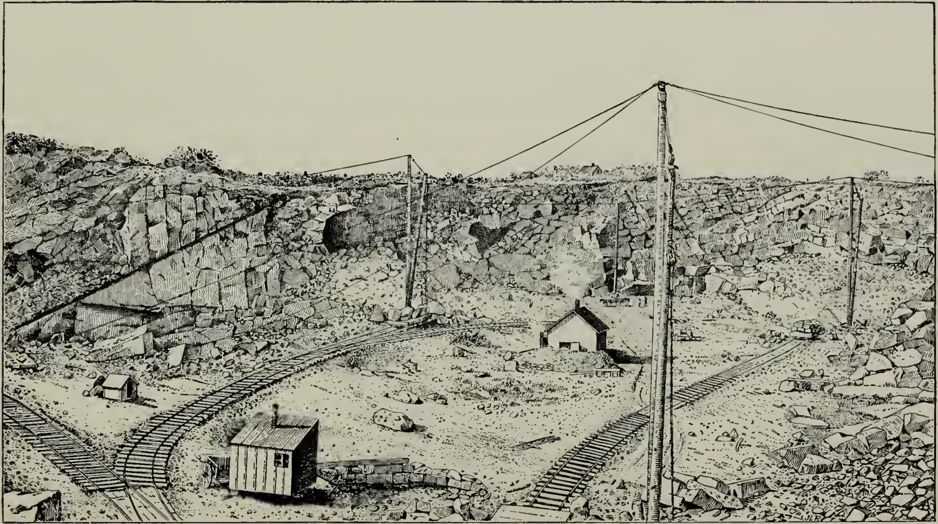
PIGEON HILL QUARRY UPPER PIT, SHOWING EXTREME DEVELOPMENT OF HORIZONTAL JOINTING.

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
265	N. 53° W		3 to 5 feet.	Diabase	
266	N. 31° W	80° NW	10 to 15°	do	
267	N. 17° E.	50° E.		do	
268	N. 27° W	85° NE.	3½ feet	do	
269	N. 33° to 53° W.		15 feet	Diorite (?)	
270	N. 25° W	70° NE.			
271	N. 13° W	70° E.			
272	N. 31° W		12 feet	Diabase	
273	N. 43° W	80° SW	2 feet	do	
274	N. 23° W	70° NE.	15 feet	do	
275	N. 15° W	75° NE.	15 feet	do	
276	N. 58° W		35 feet	do	
277	N. 58° W		10 feet	Diorite	
278	N. 33° W		15 feet	Diabase	Cuts 276.
279	N. 33° W	90°	18 feet	do	
280	N. 33° W		20 to 25 feet		
281	N. 33° W		3 to 5 feet	Diabase	
282				do	
283	N. 8° W	75° E.	15 feet	do	
283ª	N. 1° W	70° E.	1 foot	do	
283ᵇ	N. 28° W	90°	9 inches	do	
284	N. 77° E.	90°	6 inches	do	
285	N. 63° W	90°	3½ feet	do	Disappears.
286	N. 33° W	90°	3½ feet	do	
287				do	
288	N. 21° W	80° E.	1½ feet		
289	N. 13° W	85° E	3½ feet		
290	N. 28° W		4 feet	Diabase	
291	N. 9° W	80° NE.	3 feet	do	
292	N. 13° W		3 inches.		
293	N. 33° W		12 feet		
294	N. 33° W		12 feet	Diabase	
295	N. 41° W	60° NE.	3 feet+	do	
296	N. 33° W	60° SW	3 feet+	do	
297	N. 9° E.	70° NW	2½ feet	do	
298	N. 43° W	60° NE.	6 feet		
299	N. 63° W	90°	3 feet	Diabase	
300	N. 12° E.	80° NW	3½ feet	do	
301	N. 23° W		3 feet	do	
302	N. 33° W	75° NE.	2 feet 3 inches.	do	
303	N. 48° W		6 feet	do	
304	N. 13° W	85° W.	3 feet	do	
305	N. 28° W			do	
306	N. 13° W	80° E.	15 feet	do	
307	N. 38° W	70° E.	9 feet		
308	N. 62° E.	75° N		Diabase	
309	N. 21° W	90°		do (?)	
310	N. 1° W	90°	2 feet		
311	N. 13° W	90°	3 feet		
312	N. 57° E.	80° NW	3 feet		
313	N. 28° W	90°	3 feet	Diabase	
314	N. 13° W		12 feet		
315	N. 33° W	82° NE.	10 inches.	Diabase	

List of dikes of Cape Ann—Continued.

No. on map.	Strike.	Dip.	Width.	Name.	General remarks.
316	N. 35° W	85° W	5½ feet	Diabase	Cuts 317.
317	N. 23° W	75 to 85° E.	3 feet	do	
318	N. 67° W	30° SW	1½ feet	do	
319	N. 21° W	82° E	2½ feet	do	
320	N. 77° E	65° N	2 feet	do	
321	N. 87° E	68° NE	1 foot	do	
322	N. 88° W	67° NE	21 feet	do	
323	N. 18° W	69° NE	3 feet	do	
324	N. 35° W	84° NE	2 inches	do	
325	N. 8° W	75° NE	1 foot	Porphyritic diabase	
326	N. 22° W	68 to 80° E.	6 feet	do	
327	N. 23° W	48° NE	2 feet	Diabase	
328	N. 8° W	70° NE	2 feet	do	
329	N. 51° W	64° E	4 inches	do	
330	N. 78° E	80° N	3 inches	do	
331	N. 43° W	75° W	1 foot	do	
332	N. 55° W	76° W	1½ feet	do	
333	N. 37° E	66° N	1 foot	do	Cut by 331 and 332.
334	N. 48° W	75° E	1 foot	do	
335	N. 3° W	90°	1 foot	do	
336	N. 36° W	82° W	3 feet 4 inches.	do	
337	N. 28° W	86° W	3 feet	do	
338	N. 85° W	90°	10 feet	do	
339	N. 46° W	64° NE	2 inches	Porphyritic diabase	
340	N. 66° W	83° NE	2 feet	Diabase	
341	N. 57° E.		25 feet	do	
342	N. 5° W	40° NE			
343	N. 53° W	90°	2 feet	Diabase	
344	N. 43° W	90°	1 foot	do	Disappears.
345	N. [illegible]2° W	72° E	2 feet	do	
346	N. 28° W	75° NE	2½ feet	do	
347	N. 81° W	65° NE	18 feet	do	
348	N. 3° to 28° W.	83° NE	9 feet	do	Cut by 349.
349	N. 20° E	61° NW	15 inches	Porphyritic diabase	
350	N. 52° E	74° NW	3 inches	Diabase	
351	N. 29° W	85° NE	2 feet	do	
352	N. 11° E	80° NW	6 feet	do	
353	N. 33° W	60° NE	9 feet	do	
354	N. 28° W	90°	2 feet	do	
355	N. 36° W	78° W	1½ feet	do	
356	N. 43° W				
357	N. 43° W	80° E	6 feet		
358	N. 31° W		3 feet		
359	N. 31° W	80° NE	½ to 2½ feet.	Diabase	
360	N. 43° W	70° NE	3 feet	do	
361	N. 28° W	90°	2½ feet	do	
362	N. 13° W	80° NE	3½ feet	do	
363	N. 18° W		6 feet	do	
364	N. 37° W		3 to 4 feet.	do	
365	N. 21° W	60° SW	3 feet	do	
366	N. 16° W	70° W	1½ feet	do	



ROCKPORT GRANITE COMPANY'S QUARRY. SOUTH PIT, SHOWING GENERAL STRUCTURE OF ROCK AND ECONOMIC ORGANIZATION OF THE PIT; LOOKING WEST.

List of observed joint planes.

PIT I.

No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.
I.	N. 88° W.	83½° N.	XVII.	N. 71° W.	90° N.	XXXIII.	N. 33° W.	85° NE.
II.	N. 82° W.	90°.	XVIII.	N. 70° W.	84° N.	XXXIV.	N. 24° W.	82° E.
III.	N. 80° W.	88° N.	XIX.	N. 70° W.	86° N.	XXXV.	N. 23° W.	75° E.
IV.	N. 79° W.	83° N.	XX.	N. 69° W.	82° N.	XXXVI.	N. 23° W.	83° E.
V.	N. 79° W.	90°.	XXI.	N. 69° W.	84½° N.	XXXVII.	N. 23° W.	84° E.
VI.	N. 78° W.	85° N.	XXII.	N. 69° W.	88° N.	XXXVIII.	N. 6° W..	83° E.
VII.	N. 78° W.	85° N.	XXIII.	N. 68° W.	84° N.	XXXIX.	N. 5° W..	75° E.
VIII.	N. 76° W.	78° N.	XXIV.	N. 68° W.	88° N.	XL.	N. 3° W..	82° E.
IX.	N. 75° W.	84° N.	XXV.	N. 67° W.	82° N.	XLI.	N. 3° W..	78° E.
X.	N. 74° W.	55° N.	XXVI.	N. 61° W.	81½° N.	XLII.	N. 3° W..	74° E.
XI.	N. 73° W.	78° N.	XXVII.	N. 48° W.	84° NE.	XLIII.	N. 2° W.	75° E.
XII.	N. 73° W.	85° N.	XXVIII.	N. 48° W.	90°.	XLIV.	N. 2° E...	80° W.
XIII.	N. 72° W.	82° N.	XXIX.	N. 47° W.	83° NE.	XLV.	N. 9° E...	85° W.
XIV.	N. 71° W.	86° N.	XXX.	N. 43° W.	85° NE.	XLVI.	N. 40° E..	84° NW.
XV.	N. 71° W.	86° N.	XXXI.	N. 43° W.	88° NE.	XLVII.	N. 47° E..	54° N.
XVI.	N. 71° N.	87° N.	XXXII.	N. 33° W.	80° NE.	XLVIII.	N. 48° E..	54° N.

PIT II.

No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.
I.	E. and W.	60° N.	XVI.	N. 24° W.	90°.	XXXI.	N. 8° W..	72° E.
II.	N. 89° W.	73° N.	XVII.	N. 23° W.	85° E.	XXXII.	N. 30° E..	69° NW.
III.	N. 88° W.	90°.	XVIII.	N. 23° W.	84° W.	XXXIII.	N. 32° E..	65° NW.
IV.	N. 87° W.	85° N.	XIX.	N. 23° W.	72° E.	XXXIV.	N. 32° E..	70° NW.
V.	N. 81° W.	84° N.	XX.	N. 23° W.	71° E.	XXXV.	N. 32° E..	72° NW.
VI.	N. 81° W.	83° N.	XXI.	N. 23° W.	65° E.	XXXVI.	N. 32° E..	65° SE.
VII.	N. 79° W.	82° N.	XXII.	N. 23° W.	62° E.	XXXVII.	N. 35° E..	75° NW.
VIII.	N. 77° W.	76° N.	XXIII.	N. 22° W.	85° W.	XXXVIII.	N. 37° E..	70° NW.
IX.	N. 71° W.	80° NE.	XXIV.	N. 22° W.	80° W.	XXXIX.	N. 37° E..	68° SE.
X.	N. 63° W.	74° NE.	XXV.	N. 21° W.	75° E.	XL.	N. 38° E..	70° SE.
XI.	N. 58° W.	80° NE.	XXVI.	N. 21° W.	70° E.	XLI.	N. 85° E.	85° S.
XII.	N. 28° W.	84° W.	XXVII.	N. 21° W.	65° E.	XLII.	N. 86° E..	90°.
XIII.	N. 28° W.	82° W.	XXVIII.	N. 18° W.	79° E.	XLIII.	N. 87° E..	86° S.
XIV.	N. 25° W.	70° NE.	XXIX.	N. 16° W.	81° W.	XLIV.	N. 87° E..	82° S.
XV.	N. 25° W.	69° E.	XXX.	N. 13° W.	80° W.	XLV.	N. 89° E..	58° N.

PIT III.

No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.	No. of observation.	Strike.	Dip.
I.	N. 89° W.	79° N.	XII.	N. 58° W.	80° SW.	XXIII.	N. 27° E..	70° NW.
II.	N. 89° W.	85° S	XIII.	N. 58° W.	81° SW.	XXIV.	N. 37° E..	63° NW.
III.	N. 88° W.	90°.	XIV.	N. 2° E...	80° NW.	XXV.	N. 42° E..	65° NW.
IV.	N. 88° W.	85° N.	XV.	N. 5° E...	62° NW.	XXVI.	N. 50° E..	68° S.
V.	N. 88° W.	85° N.	XVI.	N. 7° E...	68° NW.	XXVII.	N. 52° E..	55° S.
VI.	N. 88° W.	82° N.	XVII.	N. 12° E..	90° NW.	XXVIII.	N. 62° E..	65° S.
VII.	N. 88° W.	78° N.	XVIII.	N. 12° E..	65° NW.	XXIX.	N. 77° E..	65° S.
VIII.	N. 86° W.	83° N.	XIX.	N. 12° E..	65° NW.	XXX.	N. 82° E..	90°.
IX.	N. 83° W.	85° N.	XX.	N. 12° E..	60° NW.	XXXI.	N. 82° E	90°.
X.	N. 83° W.	80° N.	XXI.	N. 11° E..	65° NW.	XXXII.	N. 85° E..	76° N.
XI.	N. 81° W.	78° N.	XXII.	N. 22° E..	85° NW.	XXXIII.	N. 87° E..	89° N.

PIT IV.

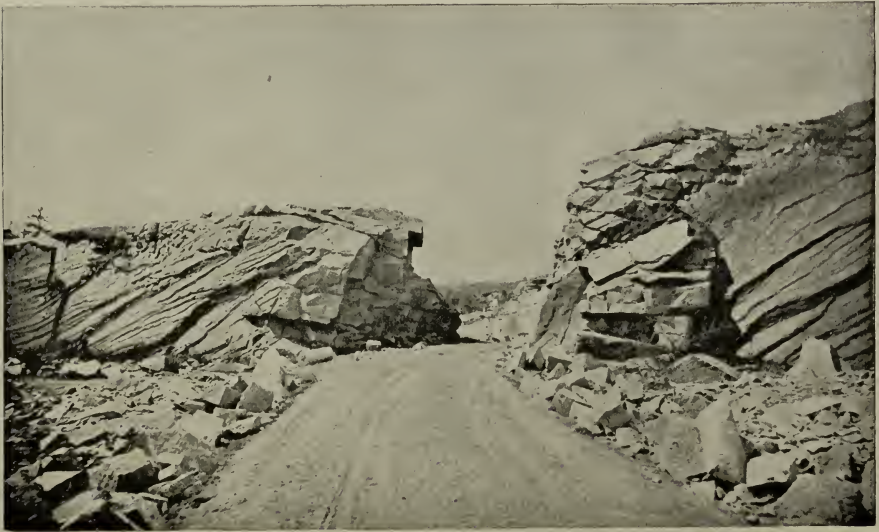
I.	N. 89° W	82° S.	XII.	N. 58° W.	68° NE.	XXIII.	N. 32° E..	84° NW.
II.	N. 88° W	78° S.	XIII.	N. 56° W.	70° NE.	XXIV.	N. 32° E .	90°.
III.	N. 88° W.	76° S.	XIV.	N. 43° W.	80° NE.	XXV.	N. 35° E..	90°.
IV.	N. 88° W.	70° S.	XV.	N. 2° E...	55° SE.	XXVI.	N. 35° E..	90°.
V.	N. 88° W.	(?)	XVI.	N. 7° E...	68° SE.	XXVII.	N. 37° E..	90°.
VI.	N. 87° W.	80° S.	XVII.	N. 7° E...	70° NW.	XXVIII.	N. 37° E..	90°.
VII.	N. 86° W.	68° S.	XVIII.	N. 12° E..	45° NW.	XXIX.	N. 37° E..	75° NW.
VIII.	N. 85° W.	75° S.	XIX.	N. 15° E..	55° NW.	XXX.	N. 37° E..	55° SE.
IX.	N. 85° W.	72° S.	XX.	N. 17° E..	64° NW.	XXXI.	N. 39° E..	90°.
X.	N. 85° W.	70° S.	XXI.	N. 22° E..	68° NW.	XXXII.	N. 57° E..	65° NW.
XI.	N. 83° W.	68° S.	XXII.	N. 25° E..	68° NW.			

PIT V.

I.	N. 89° W.	90°.	XIX.	N. 28° W.	60° NE.	XXXVII.	N. 40° E..	55° NW.
II.	N. 88° W.	90°.	XX.	N. 25° W.	65° NE.	XXXVIII.	N. 47° E..	58° NW.
III.	N. 88° W.	80° S.	XXI.	N. 25° W.	55° NE.	XXXIX.	N. 47° E..	54° NW.
IV.	N. 87° W.	90°.	XXII.	N. 23° W.	78° NE.	XL.	N. 65° E..	90°.
V.	N. 63° W.	55° NE.	XXIII.	N. 23° W.	42° SW.	XLI.	N. 67° E..	84° S.
VI.	N. 58° W.	62° NE.	XXIV.	N. 18° W.	85° NE.	XLII.	N. 77° E..	85° S.
VII.	N. 55° W.	85° NE.	XXV.	N. 18° W.	68° NE.	XLIII.	N. 77° E..	65° N.
VIII.	N. 53° W.	76° NE.	XXVI.	N. 15° W.	80° NW.	XLIV.	N. 77° E..	40° S.
IX.	N. 51° W.	58° NE.	XXVII.	N. 10° W.	90°.	XLV.	N. 82° E..	90°.
X.	N. 48° W.	77° NE.	XXVIII.	N. 8° W..	90°.	XLVI.	N. 83° E..	90°.
XI.	N. 48° W.	44° NE.	XXIX.	N. 5° W..	90°.	XLVII.	N. 84° E..	90°.
XII.	N. 46° W.	70° NE.	XXX.	N. 5° W..	90°.	XLVIII.	N. 85° E..	90°.
XIII.	N. 41° W.	45° NE.	XXXI.	N. 3° W..	90°.	XLIX.	N. 85° E..	90°.
XIV.	N. 40° W.	48° NE.	XXXII.	N. 3° W..	40° E.	L.	N. 87° E..	90°.
XV.	N. 33° W.	79° NE.	XXXIII.	N. 7° E...	58° NW.	LI.	N. 87° E..	83° S.
XVI.	N. 33° W.	72° NE.	XXXIV.	N. 7° E...	55° NW.	LII.	N. 88° E..	68° NW.
XVII.	N. 33° W.	38° SW.	XXXV.	N. 27° E..	85° SE.	LIII.	N. 89° E..	70° NW.
XVIII.	N. 30° W.	74° NE.	XXXVI.	N. 31° E..	82° SE.			

PIT VI.

I.	N. 81° W.	90°.	XVII.	N. 25° W.	60° SW.	XXXII.	N. 57° E..	82° S.
II.	N. 56° W.	63° NE.	XVIII.	N. 23° W.	72° NE.	XXXIII.	N. 67° E..	85° N.
III.	N. 53° W.	40° NE.	XIX.	N. 23° W.	65° E.	XXXIV.	N. 67° E..	82° S.
IV.	N. 53° W.	38° SW.	XX.	N. 23° W.	62° E.	XXXV.	N. 69° E..	75° S.
V.	N. 51° W.	64° NE.	XXI.	N. 22° W.	65° E.	XXXVI.	N. 71° E..	83° S.
VI.	N. 48° W.	44° SW.	XXII.	N. 21° W.	70° E.	XXXVII.	N. 72° E..	78° S.
VII.	N. 46° W.	60° SW.	XXIII.	N. 18° W.	60° E.	XXXVIII.	N. 75° E..	73° S.
VIII.	N. 45° W.	74° NE.	XXIV.	N. 13° W.	71° E.	XXXIX.	N. 77° E..	84° NW.
IX.	N. 43° W.	83° NE.	XXV.	N. 3° W..	70° E.	XL.	N. 78° E..	80° NW.
X.	N. 43° W.	75° NE.	XXVI.	N. and S.	54° W.	XLI.	N. 79° E..	90°.
XI.	N. 43° W.	80° SW.	XXVII.	N. 2° E...	55° W.	XLII.	N. 79° E..	90°.
XII.	N. 42° W.	82° SW.	XXVIII.	N. 27° E..	90°.	XLIII.	N. 81° E..	90°.
XIII.	N. 41° W.	84° SW.	XXIX.	N. 32° E..	52° NW.	XLIV.	N. 82° E..	90°.
XIV.	N. 41° W.	82° NE.	XXX.	N. 47° E..	60° NW.	XLV.	N. 83° E..	90°.
XV.	N. 40° W.	68° NE.	XXXI.	N. 47° E..	50° NW.	XLVI.	N. 84° E..	90°.
XVI.	N. 31° W.	39° SW.						



ROCKPORT GRANITE COMPANY'S MIDDLE QUARRY SHOWING FOLDINGS OF GRANITITE AT CONTACT WITH DIKE; LOOKING WEST.

PIT VII.

I.	N. 33° W.	85° W.	XIV.	N. 2° E...	80° NW.	XXVII.	N. 34° E..	70° NW.
II.	N. 28° W.	90°.	XV.	N. 5° E...	80° NW.	XXVIII.	N. 35° E .	72° NW.
III.	N. 28° W.	61° W.	XVI.	N. 7° E...	78° NW.	XXIX.	N. 35° E..	58° NW.
IV.	N. 27° W.	60° W.	XVII.	N. 7° E. .	64° NW.	XXX.	N. 37° E .	90°.
V	N. 24° W.	84° W.	XVIII.	N. 15° E..	74° NW.	XXXI.	N. 37° E..	65° NW.
VI.	N. 23° W.	60° W.	XIX.	N. 25° E..	76° NW.	XXXII.	N. 39° E.	90°.
VII.	N. 17° W.	85° E.	XX.	N. 25° E..	70° NW.	XXXIII.	N. 72° E.	77° S.
VIII.	N. 17° W.	80° W.	XXI.	N. 27° E..	68° NW.	XXXIV.	N. 77° E.	90°.
IX.	N. 14° W.	90°.	XXII.	N. 29° E..	80° NW.	XXXV.	N. 77° E.	49° S.
X.	N. 13° W.	76° W.	XXIII.	N. 29° E..	68° NW.	XXXVI.	N. 82° E.	75° N.
XI.	N. 3° W..	60° W.	XXIV.	N. 31° E..	90°.	XXXVII.	N. 87° E .	90°.
XII.	N. 1° W .	78° W	XXV.	N. 32° E..	90°.	XXXVIII.	N. 87° E..	90°.
XIII.	N. 2° E...	82° NW.	XXVI.	N. 34° E..	90°			

PIT VIII.

I.	N. 58° W.	84° NE.	V.	N. 33° W.	72° SW.	VIII.	N. 52° E.	80° NW.
II.	N. 53° W.	60° SW.	VI.	N. 47° E..	80° N.	IX.	N. 54° E .	79° NW.
III.	N. 45° W	65° NE.	VII.	N. 48° E..	79° NW.	X.	N. 59° E..	75° NW.
IV.	N. 38° W.	75° NE.						

PIT IX.

I.	N. 75° W	83° SE.	IX.	N. 51° E .	90°.	XV.	N. 60° E..	72° NW.
II.	N. 71° W	82° SE.	X.	N. 51° E..	78° SW.	XVI.	N. 63° E..	81° N.
III.	N. 65° W.	75° E.	XI.	N. 55° E .	77° N.	XVII.	N. 65° E..	74° N.
IV.	N. 61° W.	80° E.	XII.	N. 57° E.	80° N.	XVIII.	N. 69° E.	79° N.
VI.	N. 28° W.	70° E.	XIII.	N. 59° E..	90°.	XIX.	N. 70° E..	78° SE.
VII.	N. 25° W.	70° E.	XIV.	N. 59° E..	80° S.	XX.	N. 71° E.	71° S.
VIII.	N. 23° W.	71° E.						

PIT X.

I.	N. 76° W.	83° N.	VIII.	N. 31° E..	70° NW.	XV	N. 70° E	72° S.
II.	N. 76° W.	76° N.	IX.	N. 34° E..	67° NW.	XVI.	N. 70° E..	75° S.
III.	N. 32° W.	83° E.	X.	N. 47° E..	81° NW.	XVII.	N. 71° E..	54° N.
IV.	N. 23° W	90°.	XI.	N. 48° E..	83° SE.	XVIII.	N. 75° E..	70° S.
V.	N. 15° W.	80° SW.	XII.	N. 66° E..	81° S.	XIX.	N. 77° E.	73° S.
VI.	N. 10° E..	45° NW.	XIII.	N. 69° E..	70° S.	XX.	N. 84° E..	90°.
VII.	N. 27° E..	70° SE.	XIV.	N. 70° E..	83° S.	XXI.	N. 86° E..	82° S.

PIT XI.

I.	E. and W.	90°.	IX.	N. 52° W	87° SW.	XVI.	N. 32° E..	90°.
II.	N. 83° W	90°.	X.	N. 52° W	70° NE	XVII.	N. 32° E.	80° NW.
III.	N. 66° W.	83° N.	XI.	N. 52° W.	87° SW.	XVIII.	N. 34° E.	81° SE.
IV.	N. 61° W.	48° NE.	XII.	N. 48° W.	82° NE.	XIX.	N. 37° E..	62° NW.
V.	N. 58° W.	80° NE.	XIII.	N. 46° W.	90°.	XX.	N. 39° E..	75° N.
VI.	N. 56° W.	80° NE.	XIV.	N. 2° E...	64° E.	XXI.	N. 47° E.	65° NW.
VII.	N. 54° W.	87° NE.	XV.	N. 22° E..	64° NW.	XXII.	N. 49° E..	80° SE.
VIII.	N. 53° W.	90°.						

PIT XII.

I.	N. 83° W.	73° SW.	XVIII.	N. 23° W	90°.	XXXV.	N. 29° E..	85° NW.
II.	N. 75° W	73° NE.	XIX.	N. 13° W.	54° W.	XXXVI.	N. 30° E..	83° NW.
III	N. 67° W.	85° NE.	XX.	N. 3° W..	58° NW.	XXXVII.	N. 32° E	83° NW.
IV.	N. 66° W	90°.	XXI.	N. 1° W.	64° NW.	XXXVIII.	N. 32° E.	63° NW.
V.	N. 66° W.	76° NE.	XXII.	N. 2° E. .	71° SW.	XXXIX.	N. 34° E	68° NW.
VI.	N. 66° W.	64° NE.	XXIII.	N. 9° E...	60° NW.	XL.	N. 37° E	90°.
VII.	N. 63° W.	83° N.	XXIV.	N. 12° E..	60° NW.	XLI.	N. 37° E	76° NW.
VIII.	N. 60° W	90°.	XXV.	N. 17° E.	64° NW.	XLII.	N. 39° E.	90°.
IX.	N. 58° W	88° NE.	XXVI.	N. 17° E..	78° NW.	XLIII	N. 39° E.	62° NW.
X.	N. 56° W.	83° NE.	XXVII.	N. 20° E..	78° NW.	XLIV	N. 40° E.	86° NW.
XI.	N. 53° W.	81° NE.	XXVIII.	N. 20° E..	62° NW.	XLV	N. 41° E .	90°.
XII.	N. 53° W.	78° SW.	XXIX.	N 22° E..	69° SE.	XLVI.	N. 41° E..	73° NW.
XIII.	N. 46° W	70° NE.	XXX.	N. 24° E..	90°.	XLVII.	N. 41° E.	58° NW.
XIV.	N. 45° W.	75° NE.	XXXI.	N. 25° E .	84° NW.	XLVIII.	N. 42° E..	90°.
XV.	N. 41° W.	80° NE.	XXXII.	N. 26° E..	90°.	XLIX.	N. 48° E..	78° NW.
XVI.	N. 36° W.	68° NE.	XXXIII.	N. 26° E.	65° NW.	L.	N. 62° E..	83° NW.
XVII.	N. 33° W	73° NE.	XXXIV.	N. 27° E..	83° NW	LI.	N. 66° E..	90°.

PIT XIII.

I.	N. 86° W.	75° NE.	IX.	N. 30° W	87° NE.	XVI.	N. 20° E..	71° NW.
II.	N. 84° W	76° NE.	X.	N. 28° W.	70° NE.	XVII.	N. 22° E..	84° SE.
III.	N. 83° W	80° NE.	XI.	N. 12° W	80° NE.	XVIII.	N. 28° E.	78° SE.
IV.	N. 38° W.	73° NE.	XII.	N. 8° W.	78° NE.	XIX.	N 30° E..	78° SE.
V.	N. 36° W	78° NE.	XIII.	N. 17° E.	80° SE.	XX.	N. 48° E..	80° SE.
VI.	N. 34° W.	85° NE.	XIV.	N. 17° E..	73° SE.	XXI.	N. 67° E..	90°.
VII.	N. 33° W	75° NE.	XV.	N. 20° E.	83° SE.	XXII.	N. 73° E	75° S
VIII.	N. 31° W.	81° NE.						

PIT XIV.

I.	N. 39° W.	87° NE.	XV.	N. 34° E..	68° NW.	XXIX.	N. 59° E..	90°.
II.	N. 35° W.	90°.	XVI.	N. 35° E..	90°.	XXX.	N. 59° E.	90°.
III.	N, 33° W.	90°.	XVII.	N. 37° E..	83° NW.	XXXI.	N. 60° E..	90°.
IV.	N. 18° W	90°.	XVIII.	N. 40° E..	90°.	XXXII.	N. 61° E.	79° NW.
V.	N. 25° E..	90°.	XIX.	N. 40° E..	84° NW.	XXXIII.	N. 62° E..	82° NW.
VI.	N. 28° E.	70° NW.	XX.	N. 40° E..	78° NW.	XXXIV.	N. 63° E.	90°.
VII.	N. 30° E..	84° SE.	XXI.	N. 40° E..	73° NW.	XXXV.	N. 67° E..	78° SE.
VIII.	N. 31° E.	78° NW.	XXII.	N. 41° E..	74° NW.	XXXVI.	N. 71° E..	90°.
IX.	N. 32° E.	90°.	XXIII.	N. 47° E..	88° NW.	XXXVII.	N. 75° E.	90°.
X.	N. 32° E..	90°.	XXIV.	N. 47° E.	72° NW.	XXXVIII.	N. 77° E.	83° SE.
XI.	N. 32° E..	85° NW.	XXV.	N. 48° E..	90°.	XXXIX.	N. 77° E..	82° SE.
XII.	N. 32° E..	75° NW.	XXVI.	N. 49° E..	75° NW.	XL.	N. 83° E..	80° S.
XIII.	N. 32° E.	73° NW.	XXVII.	N. 50° E..	90°.	XLI.	N 84° E..	83° N.
XIV.	N. 34° E..	78° NW.	XXVIII.	N. 58° E..	82° NW.	XLII.	N 87° E..	85° N.

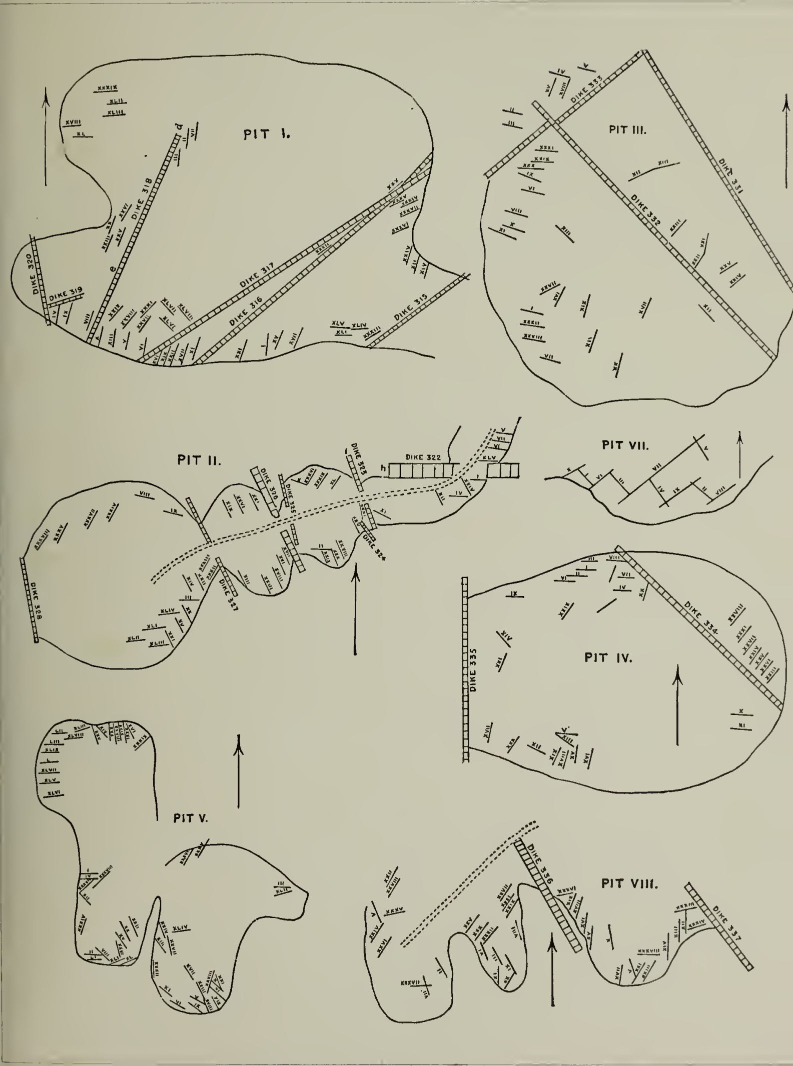


DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

PIT XV.

I.	N. 89° W.	90°.	XIV.	N. 32° W.	73° NE.	XXVII.	N. 47° E..	90°.
II.	N. 88° W.	48 to 73° S	XV.	N. 32° W.	72° NE.	XXVIII.	N. 47° E..	90°.
III.	N. 86° W.	83° S.	XVI.	N. 31° W.	75° NE.	XXIX.	N. 47° E..	90°.
IV.	N. 83° W.	90°.	XVII.	N. 31° W.	70° NE.	XXX.	N. 48° E..	90°.
V.	N. 83° W.	90°.	XVIII.	N. 28° W.	73° SW.	XXXI.	N. 50° E..	90°.
VI.	N. 73° W	85° SW.	XIX.	N. 28° W	71° NE.	XXXII.	N. 50° E..	90°.
VII.	N. 41° W.	73° NE.	XX.	N. 28° W.	82° NE.	XXXIII.	N. 52° E..	90°.
VIII.	N. 39° W.	72° NE.	XXI.	N. 25° W.	70° E.	XXXIV.	N. 57° E..	90°.
IX.	N. 37° W.	70° NE.	XXII.	N. 23° W.	83° E.	XXXV.	N. 62° E..	90°.
X.	N. 35° W.	78° NE.	XXIII.	N. 19° W.	82° E.	XXXVI.	N. 77° E..	90°.
XI.	N. 33° W.	75° NE.	XXIV.	N. 32° E..	81° SE.	XXXVII.	N. 82° E..	80° SW.
XII.	N. 33° W.	73° NE.	XXV.	N. 42° E..	80° NW.	XXXVIII.	N. 89° E..	90°.
XIII.	N. 33° W.	72° NE.	XXVI.	N. 45° E..	90°.	XXXIX.	N. 89° E..	90°.

PIT XVI.

I.	N. 86° W.	82° N.	XI.	N. 25° W.	60° SW.	XXI.	N. 34° E..	70° NW.
II.	N. 86° W.	78° N.	XII	N. 23° W.	78° SW.	XXII.	N. 36° E..	65° NW.
III.	N. 83° W.	82° N.	XIII.	N. 11° E..	65° NW.	XXIII.	N. 37° E.	80° NW.
IV.	N. 83° W.	80° N.	XIV.	N. 17° E..	62° NW.	XXIV.	N. 37° E.	72° NW.
V.	N. 81° W.	81° N.	XV.	N. 18° E .	80° NW.	XXV.	N. 37° E..	70° NW.
VI.	N. 28° W.	78° SW.	XVI.	N. 22° E..	63° NW	XXVI.	N. 38° E..	70° NW.
VII.	N. 28° W.	71° SW.	XVII.	N. 23° E..	69° NW.	XXVII.	N. 39° E..	62° NW.
VIII.	N. 28° W.	70° SW.	XVIII.	N. 30° E..	70° NW.	XXVIII.	N. 70° E..	85° NW.
IX.	N. 26° W.	58° SW.	XIX.	N. 32° E..	70° NW.	XXIX.	N. 88° E.	80° N.
X.	N. 25° W.	75° SW.	XX.	N. 34° E..	75° NW.	XXX.	N. 89° E..	80° N.

PIT XVII.

I.	N. 81° W.	90°.	XII.	N. 23° W	90°.	XXIII.	N. 16° E..	75° NW.
II.	N. 81° W.	87° N.	XIII.	N. 16° W	90°.	XXIV.	N. 17° E .	83° NW.
III.	N. 80° W.	90°.	XIV.	N. 14° W.	90°.	XXV.	N. 17° E..	81° NW.
IV.	N. 80° W.	90°.	XV.	N. 7° E...	75° NW.	XXVI.	N. 17° E..	70° NW.
V.	N. 78° W.	90°.	XVI.	N. 11° E..	88° NW.	XXVII.	N. 17° E..	69° NW.
VI.	N. 78° W	85° N.	XVII.	N. 11° E..	83° NW.	XXVIII.	N. 20° E..	90°.
VII.	N. 76° W.	90°.	XVIII.	N. 11° E..	81° NW.	XXIX.	N. 20° E..	71° SE.
VIII.	N. 73° W.	85° N.	XIX.	N. 12° E..	78° NW.	XXX.	N. 22° E..	85° NW.
IX.	N. 37° W.	80° NE.	XX.	N. 14° E..	80° NW.	XXXI.	N. 73° E..	90°.
X.	N. 25° W.	90°.	XXI.	N. 14° E..	80° NW.	XXXII.	N. 74° E..	90°.
XI.	N. 25° W.	84° E.	XXII.	N. 15° E..	78° NW.	XXXIII.	N. 77° E..	85° SE.

PIT XVIII.

I.	N. 88° W.	81° N.	XII.	N. 11° E..	68° NW.	XXIII.	N. 48° E..	60° NW.
II.	N. 88° W.	90°.	XIII.	N. 12° E..	60° NW.	XXIV.	N. 57° E..	83° SE.
III.	N. 88° W.	79° S.	XIV.	N. 17° E..	73° NW.	XXV.	N. 62° E..	90°.
IV.	N. 86° W.	85° S.	XV.	N. 17° E..	61° NW.	XXVI.	N. 64° E..	75° SE.
V.	N. 84° W.	84° S.	XVI.	N. 17° E..	60° NW.	XXVII.	N. 67° E..	90°.
VI.	N. 82° W.	80° S.	XVII.	N. 18° E..	61° NW.	XXVIII.	N. 86° E..	75° S.
VII.	N. 63° W.	81° S.	XVIII.	N. 19° E..	75° NW.	XXIX.	N. 87° E..	76° S.
VIII.	N. 28° W.	60° NE.	XIX.	N. 20° E..	65° NW.	XXX.	N. 87° E..	68° S.
IX.	N. 18° W.	90°.	XX.	N. 20° E..	65° NW.	XXXI.	N. 89° E..	90°.
X.	N. 15° W.	80° SE.	XXI.	N. 27° E..	69° NW.	XXXII.	N. 89° E..	81° S.
XI.	N. 7° E...	63° NW.	XXII.	N. 30° E..	60° NW.			

PIT XIX.

I.	N. 89° W	90°.	VIII.	N. 33° W.	68° NE.	XV.	N. 7° E...	75° S.
II.	N. 68° W	68° SW.	IX.	N. 31° W	70° NE.	XVI.	N. 47° E.	63° NW.
III.	N. 67° W.	81° SW.	X.	N. 25° W.	67° NE.	XVII.	N. 48° E.	62° NW.
IV	N. 66° W.	71° SW.	XI.	N. 23° W	64° NE.	XVIII	N. 66° E..	68° NW.
V.	N. 63° W	78° SW.	XII.	N. 23° W.	63° NE.	XIX.	N 67° E	72° SE.
VI.	N. 63° W.	70° SW.	XIII.	N. 23° W.	63° NE.	XX.	N. 82° E.	64° S.
VII.	N. 34° W.	61° NE.	XIV.	N. 23° W.	58° NE.			

PIT XX.

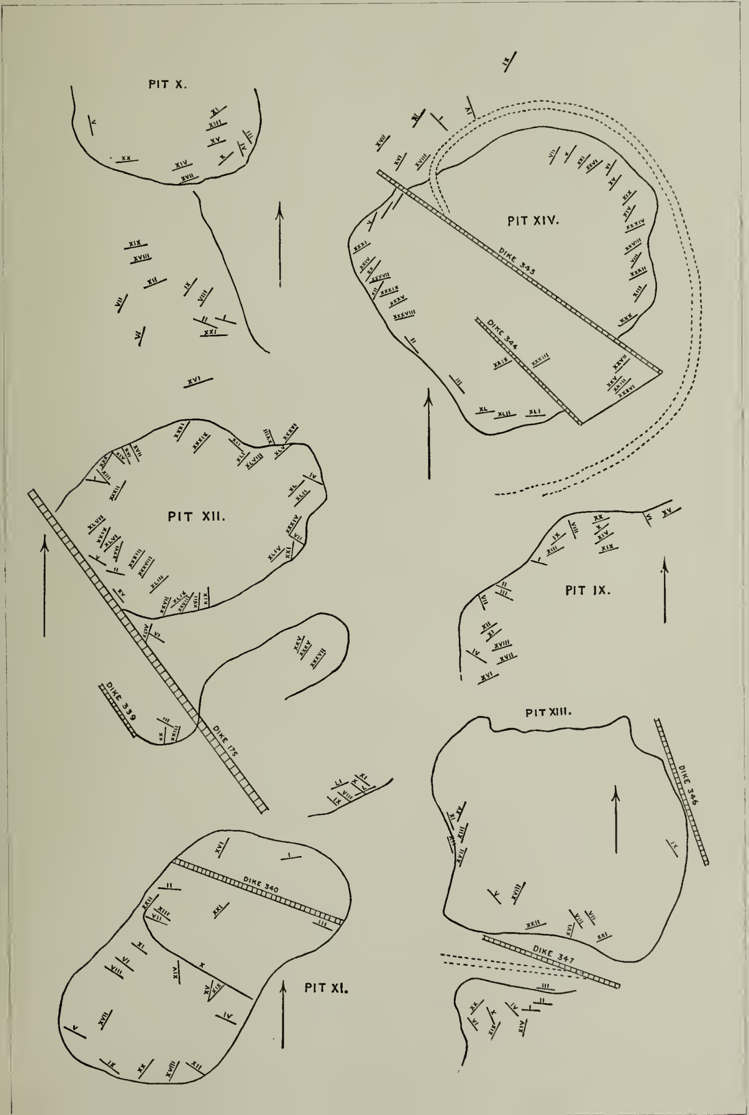
I.	N. 78° W.	62° NE.	VI.	N. 1° W.	75° E.	X.	N. 67° E .	82° N.
II.	N. 73° W.	55° SW.	VII.	N. 2° E...	90°.	XI	N. 69° E..	82° N.
III.	N. 58° W.	78° SW.	VIII.	N. 2° E .	65° SE.	XII.	N. 70° E	85° N.
IV.	N. 33° W.	73° SW.	IX.	N. 49° E	60° NW.	XIII.	N. 77° E .	74° N.
V.	N. 7° W..	90°.						

RIFTING OF THE QUARRIED ROCKS.

The quarried rocks of Cape Ann exhibit, as do those in other parts of the country, the phenomenon of "rifting" in an interesting manner. It is owing to the existence of this feature that the imperfectly jointed rocks of this region are so serviceable to the quarryman. By the term "rift" is indicated an incipient fracture in the rock which has not developed in the form of a joint plane. No very distinct passage has been seen between the incipient fracture of the rifting and the perfect joint planes. At one point between the two great quarries at Bay View, where the rift has been subjected to the action of the weather on the old glacial surface or on a surface which has been for some time bared to the weather, the rifting appears as visible fractures, not averaging more than a quarter of an inch apart and extending for a distance of two feet through the rock. In yet other cases, joints which have a development of chloritic and epidotic material on the side of the fracture, known to the quarrymen as "green seams," pass rather more distinctly into the rift planes than do the ordinary joints.

Quarrymen, for convenience of description, divide the rift lines along which their rock fractures into two divisions, which are generally found in quarries, viz, the "rift" and the "cut-off." The most manifest of these, whatever be the direction, they term the rift. A set of joints at an angle of about 65 degrees to the rift they call the "cut-off." Sometimes a third system of incipient fractures is found nearly horizontal, which they term "lift." No other planes of fractures save those three are found in the granites of Cape Ann. Indeed, the third line of fracture is more frequently absent than present.

The peculiar feature of all these incipient fractures is that they appear only where the rock has been exposed to the weather or to


PIT X.
PIT XIV.
DIKE 343
DIKE 344
PIT XII.
DIKE 339
DIKE 175
PIT IX.
PIT XIII.
DIKE 346
DIKE 347
DIKE 340
PIT XI.

strain, while the joints, though not readily visible, appear evident on close inspection as far as the tendency to split on their planes extends.

When broken along the rift planes the faces of the fracture are much rougher than the faces exhibited by the deeper joint planes. This at first sight seemed to indicate that the character of the fractures and faults was essentially different from that artificially developed on the rift lines. It may be, however, that the processes of decay and replacement brought about by the action of the weather along the joint planes has caused this difference. It is also noticeable that where the rock is broken across the rift axes it commonly assumes the conchoidal fracture, and has in all cases the surface much more rough than that of the fractures which have developed along the rift planes. This is evidently due to the fact that in the conchoidal fracture the splitting turns around the crystals more than it does when the splitting is along the rift.

Although it is not yet certainly the case, it seems likely that there is a relation of a genetic sort between these fractures of the rift and those which are expressed in recognizable joint planes. In some of the quarries there is a manifest connection between the two. Thus in the Bay View quarries the most evident rift agrees exactly in direction with the most conspicuous set of joint planes. Elsewhere the relation can not be so well made out. It may be also noted that in one case the most evident rift plane on one side of a dike appeared to be indicated but extinguished on the other side of the intrusion.

Microscopic examination shows that the rifting probably occurs under the following conditions: The mass of granite, like that of other holo-crystalline rocks, is made up of material, all of which is arranged with reference to definite crystalline axes, but these axes are disposed in an entirely irregular manner. These crystals each have planes on which breakage will more readily occur than on other lines. Now, some of these crystals, the feldspar and hornblende at least, have lines along which they fracture with certain readiness. Such fracture planes are not known to exist with quartz, but it may also have axes on which breakage is somewhat more easy than in other planes. Moreover, in all these crystals, whatever the shape of their periphery, the line of juncture with the neighboring crystals is always somewhat irregular. Now, if a mass of this rock by strains is urged to fracture, the plane of rupture will be formed at some points by breaking through the crystal along its line of weakness, and in a general way coincide with the run of the rupture plane. In other cases the rupture will follow around the adjacent faces of the crystals. Microscopic sections show that something like this action has taken place. Along the lines of the rift where they cut through a feldspar crystal, although the evidence of displacement is obscure, the existence of a rupture is shown by the presence of a distinct fault breccia, the fragments of the breccia having been afterwards cemented together with quartz, or, perhaps, by other minerals.

It seems likely that the amount of dislocation attendant on the formation of these fractures is extremely small, but this amount has not yet been determined. It seems also probable in all cases that the fracture is practically closed by the secretion of cement, which has bound the walls together. It may well have been that these several separate sets of fractures, those of the rift, the cut-off, and lift, were formed at different times, and were in turn more or less completely healed by exudations from the walls. Although these walls are at least in part fixed together, when the quarryman disrupts the mass, fractures more readily occur along these old planes than in any other direction.

The difficulty in identifying the rift structure with the joint planes arises from the fact that the joint planes are generally remote from each other in a far greater degree than those of the rifts, there being, in effect, no passage between the two classes of ruptures. If joint planes are genetically connected with rift planes, then it must have been that by the application of some force after the rifts were formed certain of the fracture lines at remote intervals were by secondary strains developed into joints.

Even if we could account, as it seems likely we may, for certain of the joint planes on this hypothesis, there remain, as the foregoing statements concerning joints show, many others which can not be referred to planes of rifting. It seems pretty clear that there is not an indefinite number of rift planes in the mass of the rock, while the number of positions of the joint planes is practically indefinite. Although the rift planes exist in a great portion of the rocks of Cape Ann there are some considerable irregularly disposed areas in the quarries, which appear in good part, if not entirely, destitute of these potential fracture lines. So far it has not been possible to secure any clue as to the relations of these non-rifted areas.

There is a practical point which comes out of this consideration concerning the value of rifts and joints to the quarryman's work. In general the joint planes of our crystalline rocks are disadvantageous to the quarryman. In certain cases they serve his needs, but oftener with a number of these fracture lines they break up the rock into inconvenient forms. Moreover, the joint planes, even where useful, are apt to become less distinct as depth is attained. On the other hand, the rift, though variable in amount and direction, appears to be a permanent feature in granitic rocks, and on the relation of the planes to each other depends in a large measure the serviceability of the material for architectural purposes. It therefore is well for persons undertaking costly work, connected with the stripping away of parts of the rock which are affected by water and other

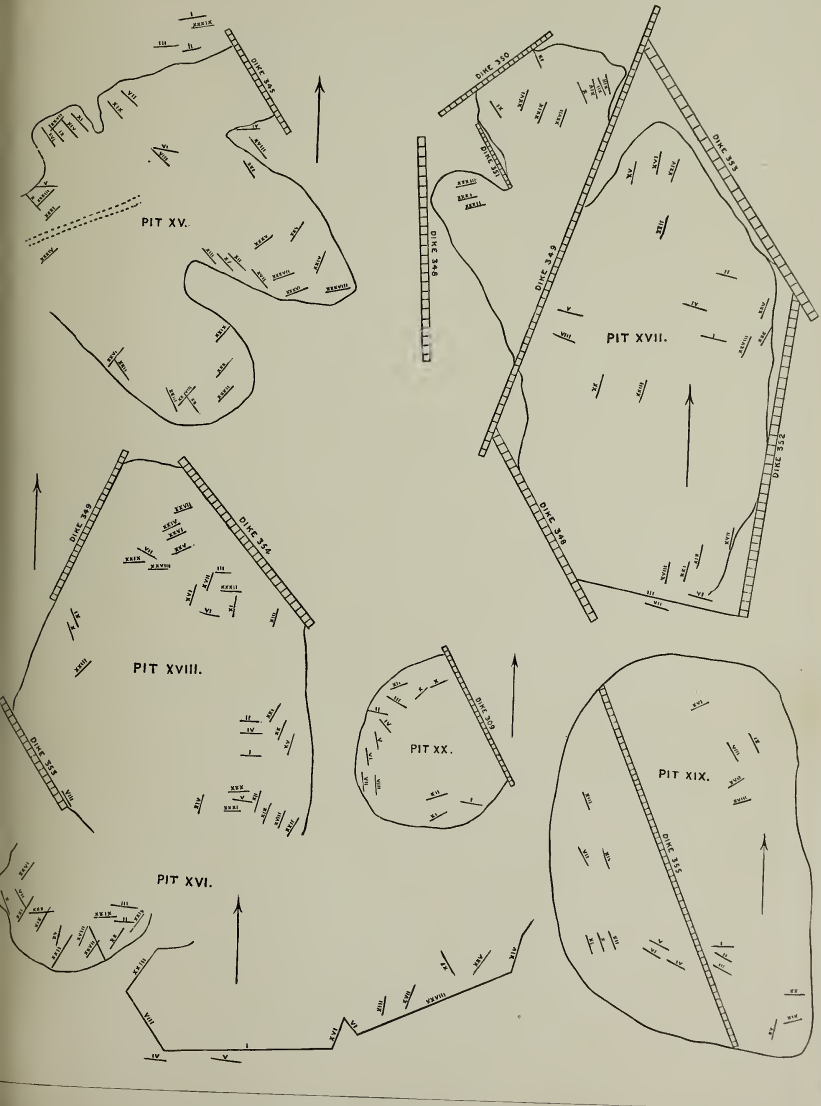


DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

agents of superficial decay, to determine the character of the incipient rift fractures with reference to the end in view.

THE GENERAL PETROGRAPHY OF CAPE ANN.

The bed rock on the island of Cape Ann is mainly granite cut in various directions by diabase and other dikes. This granite has been studied by several geologists, and has been called syenite, granite, and granitite. Dr. M. E. Wadsworth, who has made the most careful petrographic studies in this region, has decided the rock to be hornblendic granitite, and the studies made in preparation for this report point to the same conclusion. In a dozen microscopic slides cut from specimens collected at various points on the island a very nearly uniform character is observed. Quartz and orthoclase feldspar form the bulk of the rock, with black hornblende and biotite as the two other essential constituents. The feldspar is often microline. Both the quartz and feldspar are very much strained and broken, exhibiting distinct lines of weakness which develop the rift of the rock.

Besides these essential minerals we find the usual accessories of granite, plagioclase feldspar, magnetite, limenite, chlorite, apatite, zircon, epidote, and fluorite. The mineral danalite, which Dr. J. P. Cooke described from Rockport, also occasionally occurs. It resembles garnet in the slide, as well as when macroscopically examined.

All the quarries on Cape Ann are in rock having a uniform character as above described. At those exposures the biotite and hornblende vary somewhat in abundance ; but aside from this there is very little local modification in the character of the rock. On the sea shore, however, we observe that there are considerable variations in its texture and composition. In some places it is very fine grained ; again it becomes extremely coarse and almost porphyritic. In some cases the granite weathers easily; in others it is very durable. The rock often becomes very syenitic, and in one locality, in a railroad cut on the Eastern Railroad line, near the Magnolia station, the almost total absence of free quartz makes the rock, at least locally, a true syenite. It is possible that in some cases these variations may be caused by injections of granitic dikes through the bed rock ; although in no case has it been possible to prove this hypothesis.

The islands lying near the shore—Milk, Salvages and Thatcher's—present a more difficult problem. Their complete isolation from the main mass and separation by a rather deep trough may indicate a line of weakness occupied by some more easily eroded rock, or perhaps may represent the line of contact of two distinct granitic injections. The petrographic evidence on this point is not complete. The bed rock on these several islands, while being essentially the same, differs widely in character from that on the mainland. Whether this be due simply to local variations in the Cape Ann mass, or whether it marks a distinct ejection, has not been determined.

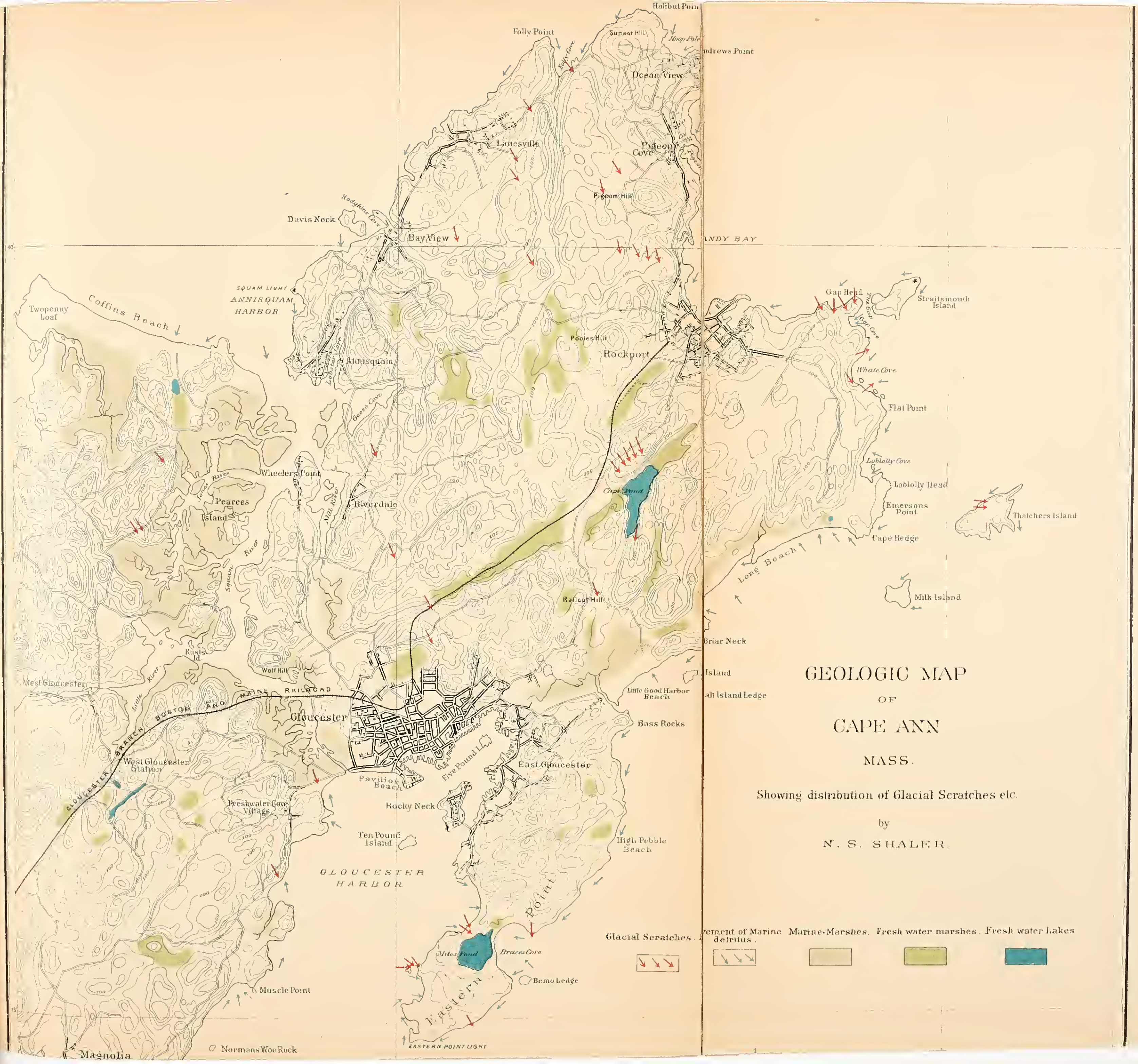
Macroscopically, the rock on the above-named islands differs from that on Cape Ann in being much darker, in the greater abundance of hornblende and magnetite, in containing much less quartz, and in having a darker colored feldspar. Quartz is quite common as minute crystalloids, and the feldspar often occurs in the form of Carlsbad twins and as microline. The general absence of macroscopic quartz is sufficiently well marked to place the rock among the syenitic granites. There is a frequent tendency to the porphyritic character. No distinction between these rocks has been made in the accompanying map of the bed rock.

In the vicinity of Squam River an area of diorite has been found occupying the position indicated upon the map. The depression occupied by Squam River is one of the most marked features in the topography of the region. On either side are high hills, and the center of the Reach is considerably below sea level, although it is much encumbered by glacial drift. To explain this valley was for a long time a difficult problem. It appeared quite evident that it must indicate a line of weakness in the granitite, though the nature of this remained undetermined. The general agreement between the trend of the valley, and the strike of the principal set of dikes and their abundance in that vicinity, suggested an explanation which lacked proof. For some time the presence of this diorite was unperceived, and it was considered a mere fine grained variation of the Cape Ann granitite.

This diorite is very light colored, has a very glassy feldspar and some quartz, so that until the microscope was used its true character was undiscovered. The rock is finer grained than the granitite, is a trifle darker, and has a much more complicated development of joint planes. Instead of the great massive jointing so typical of granitite, the rock is cut into small blocks by numerous unsystematically arranged joint planes. This, however, served as no guide, for the granitite is occasionally cut by equally frequent joints.

Petrographically, the rock is composed of plagioclase feldspar, with much biotite and hornblende. Quartz is often very abundant, orthoclase feldspar, apatite, and zircon occur occasionally.

It is difficult to determine which of these two rocks is the older. The region is so drift-covered that the contact can not be seen; but wherever it is approached the granitite becomes markedly porphyritic; in some places, however, as for instance on the hill called "The Poles," in Gloucester, the diorite exhibits the same phenomenon. The contact effects are not uniformly well marked, which may be explained by the supposition that at the time of the injection of one of the masses the other was still very much heated. No dike of granitite has been found cutting the diorite, nor does this rock, so far



GEOLOGIC MAP

OF

CAPE ANN

MASS.

Showing distribution of Glacial Scratches etc.

by

N. S. SHALER.

as observed, send tongues into the granitite. In several places, notably on the road to Coffin's Beach, and in the vicinity of Bond's Hill, on the west side of Squam River, opposite the city of Gloucester, the diorite is in such a position as to indicate that it is included in the granitite. Owing to the abundance of drift, this point in any of these localities can not be definitely settled. The first impression was that we had here a great dike of diorite cutting the granitite; but every indication in the field points to the opposite conclusion, namely, that the granitite has burst up around this diorite, leaving it as an included mass.

The mass of diorite is apparently of an irregularly circular form, having its center at about the middle of the Annisquam Reach on Rust's Island. On all sides where the rocks outcrop, it is surrounded by granitite, the two entrances of the Reach being the only places where it could possibly have cut the granitite. These entrances are narrow and are bounded on either side by granitite which is not porphyritic, which facts almost exclude the hypothesis that the diorite has cut the granitite. The porphyritic character of the granitite in many places is remarkably well developed; but nowhere better than at West Gloucester, near the Russian Cement Company's factory. The granite porphyry at this point has fine, large porphyritic crystals of quartz and feldspar in a ground mass composed mainly of the same minerals. It is very finely jointed, as may be seen in the picture of the post-glacial talus. (See Pl. L.) The approach of the diorite and granite is generally, though not invariably, marked by a distinct drift-filled valley. The granite as it approaches the contact is very much broken, and, even when not porphyritic, quite different from the typical Cape Ann granite.

The abundance of hornblende, the character of the feldspar, and the general absence of quartz, all render this rock open to the attack of the elements. This weakness is enhanced by the character of the jointing, both in this diorite and in the surrounding granite.

Some petrographic study has been given to the phenomena of inclusions, veins, segregations, dikes, decomposition and rift as observed in the granite of this island. Veins and segregations are both quite commonly found. In the Rockport quarry, pockets exist in the granite containing quartz and feldspar, intergrown to form the so-called graphic granite. In connection with these, are large nodules of smoky and milky quartz, masses of green feldspar, and small segregations of magnetite, frequently containing on their edges small, perfect prisms of zircon, terminated by pyramids with convex faces. Fluorite and danalite also occur in these veins in considerable masses. On the sea shore, little pockets and veins of graphic granite, blue quartz, feldspar, hornblende, and magnetite are often found, though they are by no means as common as in other regions on the New England coast.

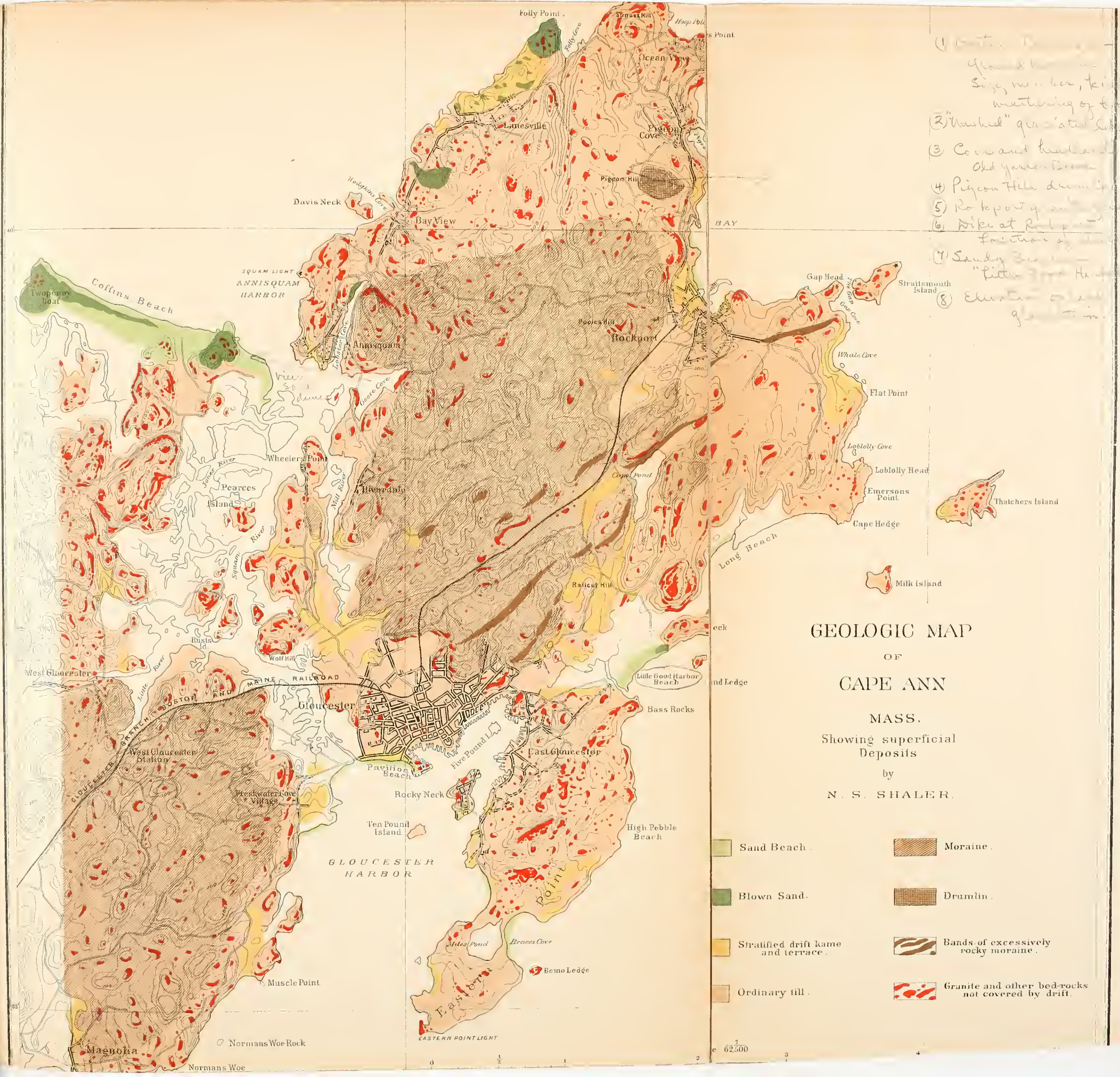
Basic segregations, the "black patches" of the quarrymen, are met with in all the quarries. These are irregular, bluish patches, composed of feldspar and the more basic of the granitic constituents fading quite gradually into the true granitite. These patches represent the remnants of original segregations of the more basic elements from the granitic magma, before the final cooling of the mass. The variations in the hue, from a light blue to a very dark shade of the same color, depends upon the abundance of hornblende and magnetite which occur in fine grains scattered through the feldspar and quartz ground mass. In the slides, these basic segregations show the ordinary granite minerals in very fine grains, and in different proportions from that of the true granitite. Both orthoclase and plagioclase feldspar occur, the latter being rare; fine grained quartz is very abundant; hornblende and magnetite are common; and there is some biotite. The microperthite intergrowth of feldspar is extremely well shown, and Carlsbad twins are found everywhere. The effect of strain is shown in all the quartz grains of sufficient size.

True inclusions of other rocks are not commonly met with in the granitic material. Near the contact of the granitite with the diorite in the West Gloucester district, apparent inclusions of diorite are common. In other parts of the region undoubted inclusions of dioritic and gneissoid rocks are found. Instances of the latter kind of inclusions were noticed on Davis' Neck, and at various other points along the Bay View and Lanesville shore. From the large number of included fragments, on this northwest shore of the island, one might be led to suspect that the locality is near the contact of the granitite with gneiss which may occupy the bed of Ipswich Bay.

Wherever any area of an acre or more of rock is bared by the waves, or by the quarryman's work, we find dike rocks cutting the granite. As before described, over three hundred and fifty dikes have been observed, mainly upon the sea shore line. The dikes, being more easily eroded than the granitite, seldom outcrop in the interior region. There can be no doubt that they are as abundant here as on the sea shore and their positions are often suggested by narrow drift-filled chasms in the granitite.

No thorough petrographic study has been made of any of these dikes; but a few of the more interesting ones have been subjected to a cursory microscopic examination. In general, it may be said that the dike rocks are either diabase or quartz porphyry, and these two general divisions only have been adopted in the accompanying map of the bed rock. Numerous subdivisions might be made upon the basis of the ground mass or special variations of mineral composition, but no attempt has been made to do so.

Dikes numbered on the map as follows have been found by a microscopic examination to be diabase: 5, 9, 57, 61, 91, 131, 150, 175, 201,



GEOLOGIC MAP
OF
CAPE ANN
MASS.
Showing superficial Deposits
by
N. S. SHALER.

(1) [illegible] [illegible] —
Ground moraine
Size, number, kind and weathering of [illegible]
(2) "Washed" [illegible] [illegible]
(3) Cove and headlands [illegible]
Old [illegible] [illegible]
(4) Pigeon Hill drumlin
(5) Rockport [illegible]
(6) Dike at Rockport
formation of [illegible]
(7) Sandy Beach —
"Little Good Harbor Beach"
(8) Elevation of land after glaciation.

217, 229, 264, 276, 277, and 299. They have the ordinary diabase composition, most being porphyritic; some holocrystalline; others cryptocrystalline. No signs of glass are present though the contact is often very fine grained and dense and may be composed of devitrification products. Lath-shaped plagioclase crystals are always present both as porphyritic crystals when the rock is porphyritic and in the ground mass. It is sometimes very clear and glassy; but more often somewhat decomposed. In some cases complete sausaurization results. Signs of paramorphism are not wanting. Brown and very pleochroic biotite is common as a primary constituent and also as a secondary product. It contains the usual diabase inclusions and alters readily to chlorite. Fine crystals of augite occur in the porphyrites, in some cases being pleochroic, but generally clear and colorless or pale green. The ground mass is frequently one-half augite. It decomposes readily to chlorite, green hornblende, magnetite, etc., until often no trace of it is left in the rock. This is the case in dikes Nos. 91 and 299. Muscovite, calcite, magnetite, iron pyrite, apatite, epidote and other products of decomposition are common in the slides made from all these dikes. In one case olivine was also present. No. 175 is a large dike of metamorphosed diabase porphyry 18 feet in width and extending several miles in Rockport and Pigeon Cove. It has extremely large plagioclase feldspar crystals several inches in length, often very much decomposed. The ground mass is holocrystalline, made up of very much decomposed lath-shaped plagioclase, hornblende, chlorite and magnetite mainly. The augite has almost completely disappeared in some cases, remaining simply as a core within a mass of green hornblende.

Only one dike, No. 237, has been studied, which can be called diorite, although many are so metamorphosed that no augite is present. This No. 237 is a very interesting dike of diorite porphyrite. It is very much faulted, and occurs at various points along the entire Lanesville shore. It has large crystals of feldspar, several inches in length, finely striated and very iridescent, hence probably labradorite. The feldspar is extremely decomposed to kaolin, muscovite, calcite, etc. Secondary green hornblende and biotite occur along the cracks in the feldspar and in bunches throughout the mass. The rock is undoubtedly very much altered from its original state, and a careful study of it will be made and reported upon later.

There is considerable quartz and feldspar porphyry among the Cape Ann dikes. Nos. 3, 53, 127, 135, 147, 182, and 184 are of this character. No. 3 has porphyritic crystals of plagioclase and orthoclase feldspar and rounded quartz considerably resorbed. The ground mass is microgranitic, mainly quartz, feldspar, and hornblende, mostly the very pleochroic blue variety glaucophane, which gives a decided blue color to the rock. No. 53 has porphyritic crystals of feldspar with distinct outlines, but somewhat decomposed. The ground mass is a confused aggregation of vesicular needles of brown hornblende, with clear spaces quite granophyric. This appearance may be primary, but it gives one the impression of felsite with a glassy or microfelsitic base altered to this condition.

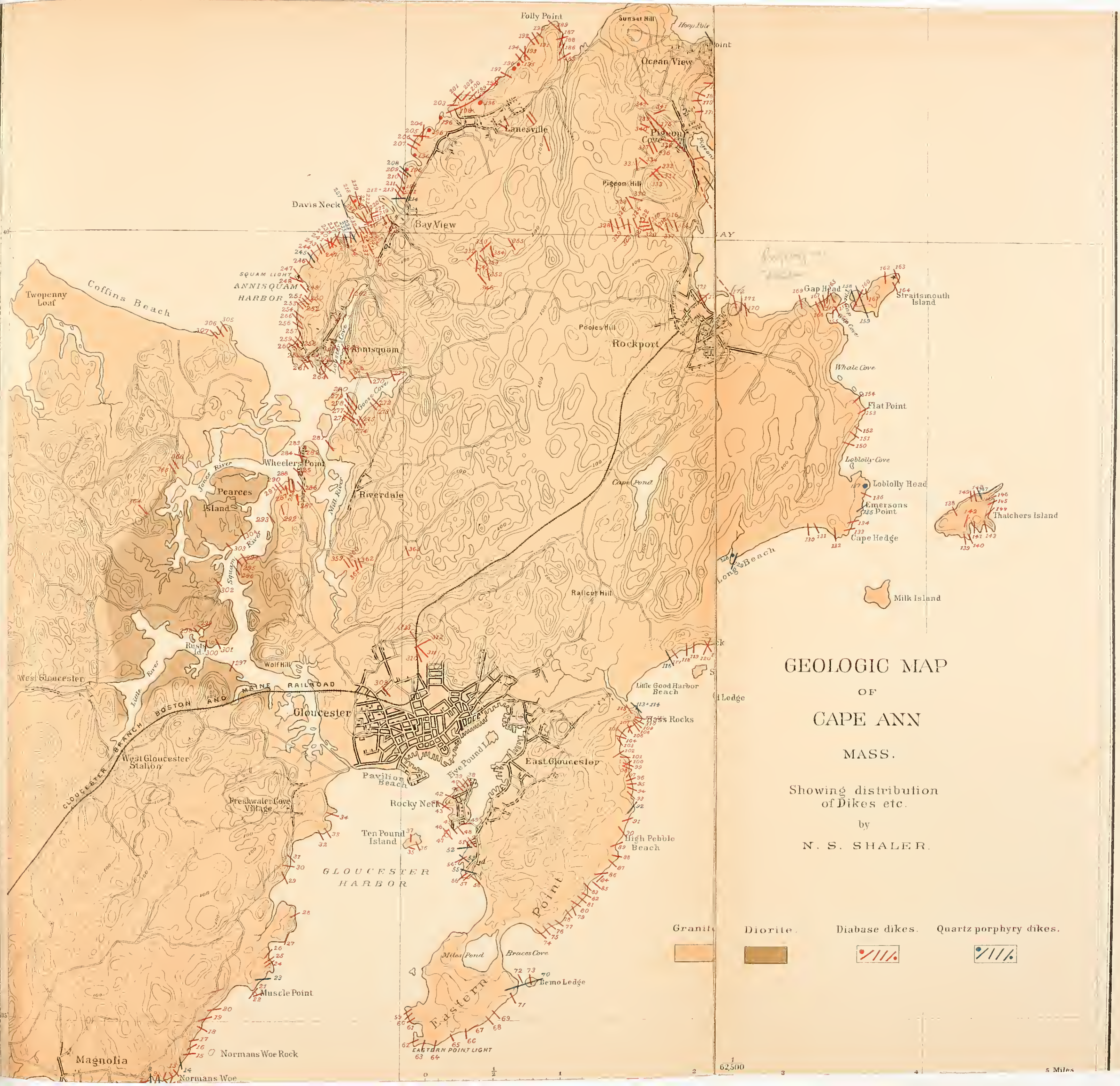
Nos. 127 and 135 are more typical quartz and feldspar porphyries. They occur as faulted and very irregular dikes, in some places, as at 127, looking like chimneys cutting the granite. Wherever a contact has been observed between the diabase dikes and quartz porphyries, the latter are found to be the older, and their ragged outline would indicate that they cut the granite before the joint planes were formed, for they never follow any system of joints and are often faulted along the line of joint planes. These dikes have the usual character of quartz porphyry. Embayed porphyritic crystals of quartz and feldspar exist in a ground mass of quartz, feldspar, hornblende, and biotite. In the center the ground mass is quite holocrystalline, but at the contact it becomes cryptocrystalline. No glass or microfelsite is found, although the structure leads one to suspect that these conditions once existed, and that the present structure is the result of devitrification.

Nos. 182 and 184 are narrow schistose dikes, apparently very much altered. They are fine grained, and composed of a mass of undecomposed feldspar, quartz, and blue hornblende—glaucophane. The rock shows signs of flow structure, and might be a gneissoid rock as well as a feldspar porphyry, but in places it has indistinct porphyritic feldspar crystals. The field evidence shows that they are dike rocks and the crystals look like porphyritic feldspars rather than crystals of secondary origin. Dike 135 has the quartz crystals very much faulted, and the cracks filled with the ground mass. In one place the graphic granite structure shows. The extensive cracking of the quartz grains seems to show that it has undergone some of the movements which have jointed the granite. The joints, too, are not all such as can be explained by cooling alone.

No. 147, on Thatcher's Island, is an interesting dike of quartz porphyry, which shows a beautiful spherulitic structure. It has a cryptocrystalline ground mass of quartz and feldspar with porphyritic crystals of the same. A more thorough petrographic study will be made of some of these dikes, the object in this report being simply to indicate their general character.

INFLUENCE OF GEOLOGICAL STRUCTURE UPON THE HEALTH OF THE DISTRICT.

Although the general position of Cape Ann should be favorable to the health of its inhabitants, the vital and sanitary statistics show that the area suffers from certain classes of maladies, known as zymotic diseases. It is probable that these evils are caused in part at least by the failure to recognize the important fact that the soil of


GEOLOGIC MAP
OF
CAPE ANN
MASS.
Showing distribution of Dikes etc.
by
N. S. SHALER.
Granite
Diorite.
Diabase dikes.
Quartz porphyry dikes.
Folly Point
Sunset Hill
Hoop Pole
Point
Ocean View
Lanesville
Pigeon Cove
Pigeon Hill
Davis Neck
Bay View
Squam Light
Annisquam Harbor
Twopenny Loaf
Coffins Beach
Annisquam
Lobster Cove
Goose Cove
Pooles Hill
Rockport
Gap Head
Straitsmouth Island
Whale Cove
Flat Point
Loblolly Cove
Loblolly Head
Emersons Point
Cape Hedge
Thatchers Island
Long Beach
Milk Island
Cape Pond
Ralicut Hill
Wheelers Point
Jones River
Pearces Island
Squam River
Mill River
Riverdale
Rust Id.
Little River
Wolf Hill
West Gloucester
Boston and Maine Railroad
Gloucester Branch
West Gloucester Station
Gloucester
Little Good Harbor Beach
Bass Rocks
Pavilion Beach
Five Pound I.
East Gloucester
Rocky Neck
Ten Pound Island
Freshwater Cove Village
Gloucester Harbor
High Pebble Beach
Eastern Point
Miles Pond
Braces Cove
Bemo Ledge
Eastern Point Light
Muscle Point
Normans Woe Rock
Normans Woe
Magnolia
1/62500
0
1/2
1
2
3
4
5 Miles

this peninsula is of a peculiar character. Almost all the other coast towns of New England are in the main underlain by permeable drift, kames, or other detritus, containing little or no clay. As will be seen from the map, nearly the whole of Gloucester and Rockport rest upon till. Even where there are materials affording ready passage to ground water, the bed rocks are often very near the surface and thus the sewage is unable to penetrate to any great depth and becomes mixed with the water of the wells. At least three-fourths of the sources of domestic water supply on the Cape from wells and springs are liable to contamination. I know no other equal area in Massachusetts where the sources of potable waters are in general so objectionable as in these two towns of Gloucester and Rockport. Recently the city of Gloucester has provided itself with a system of water supply drawn from a tolerably satisfactory source west of Annisquam River; but a large part of the water in that city is still obtained from wells, and the villages of Rockport, Pigeon Cove, Lanesville, Bay View, and Annisquam are dependent on such sources of supply.

It will be easy to remedy these difficulties at a relatively small cost. The unsettled region of the great moraines, the section commonly known as "Dogtown Commons," contains an area of several square miles of land which at present has very little value. A thousand acres of this land in the center of the island should be reserved for water supply. This morainal matter is so permeable to water that wells of no great depth placed in the center of such a reservation would afford a sufficiency to supply all the settlements along the coast line. This water would be obtained at such a height that the costs of pumping would be small. The land for such a source of supply could probably be obtained at the present time at a small cost, and the maximum distance from the source to the furthest of the shore settlements would not exceed three miles. An incidental advantage arising from such a reservation would be found in the fact that it might in time be made a park of value to all the settlements on this island.

THE STRUCTURE OF MONUMENT MOUNTAIN IN GREAT BARRINGTON, MASSACHUSETTS.

BY

T. NELSON DALE.

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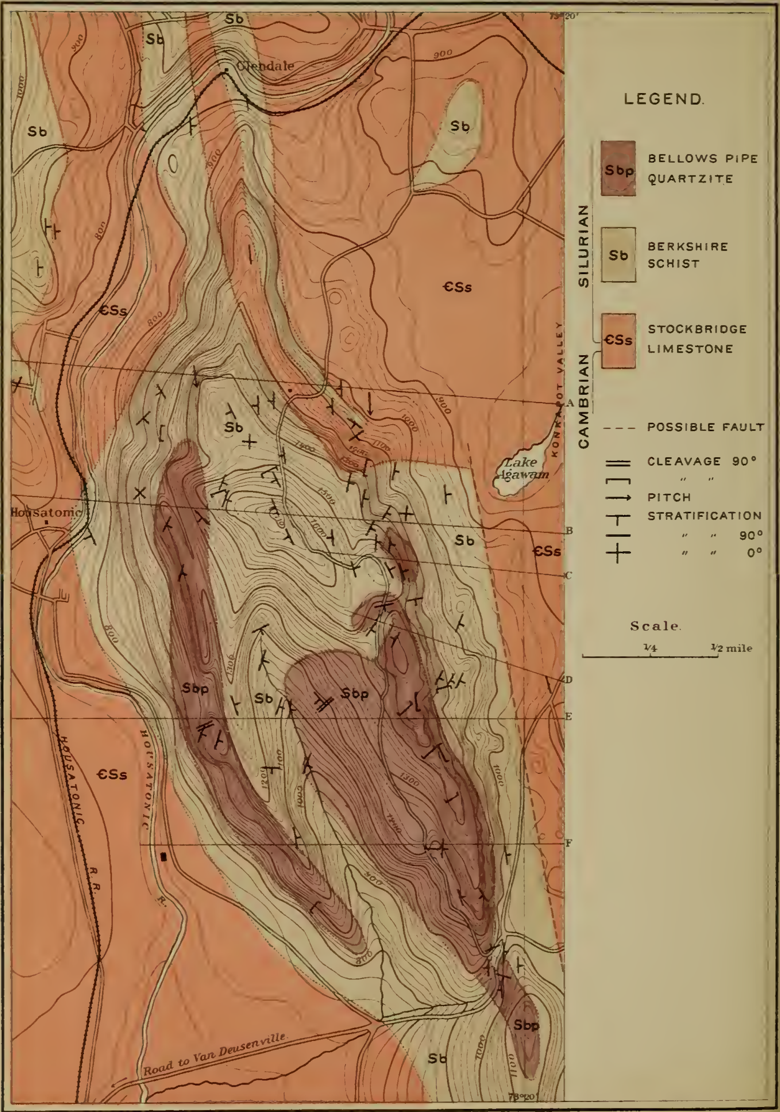

TOPOGRAPHY BY U.S. GEOL. SURVEY.

GEOLOGY BY T. NELSON DALE.

MONUMENT MOUNTAIN BERKSHIRE CO. MASSACHUSETTS

THE STRUCTURE OF MONUMENT MOUNTAIN IN GREAT BARRINGTON, MASS.

BY T. NELSON DALE.

PHYSIOGRAPHY.

Monument mountain forms part of a range of hills between the Taconic range (Silurian) on the west and the Hoosac range (Cambrian and pre-Cambrian) on the east, extending from a little south of Pittsfield to the vicinity of the village of Great Barrington, a distance of about 18 miles. It lies in the line of the Greylock synclinorium, from which, however, it is cut off by the broad limestone plain about Pittsfield. Owing to the westward offset in the Hoosac range between Lee and Stockbridge, Monument mountain lies but 2 miles west of the pre-Cambrian gneisses (Beartown mountain). Its area is only about 3 square miles; its higher parts range from 1,640 to 1,710 feet above the sea level and from 740 to 950 feet above the adjoining valleys; its general form is not unlike that of an old-fashioned bootjack, sending out a central spur to the north and two lateral ones to the south. These southern spurs present to the east and west precipitous cliffs of quartzite several hundred feet in height, with considerable talus below. The

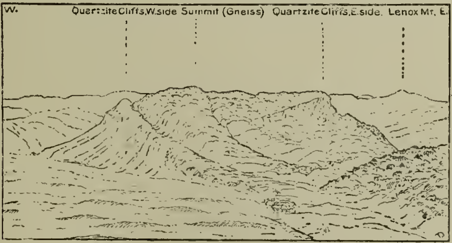

FIG. 65.—Monument mountain, south side, from Mount Keith, in Great Barrington.

contour map (Pl. LXXI), in connection with the sketches from the south and the west (Figs. 65 and 66) will serve to complete the description of its general features.

Although of such inconsiderable area and altitude, and, as will be shown, of apparently simple geological structure, Monument mountain offers a structural problem of no little difficulty, as may be gathered from the various hypotheses as to its structure advanced by Prof. Dana.[1] The dip symbols on the map record the structural data obtained by the writer in in 1889.

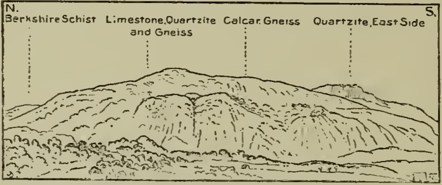

FIG. 66.—Monument mountain, west side, showing the quartzite masses on both sides of the central schist and gneiss mass. North of the top several feet of quartzite are interbedded with some limestone.

PETROGRAPHIC STRATIGRAPHY.

As the petrographic character of the various beds is sufficiently complex to increase the difficulties of structural interpretation, this part of the subject will be first dwelt upon. The petrographic examinations were made by Mr. J. E. Wolff, of this Survey. There is no difficulty in recognizing the Stockbridge limestone from its outcrops north of Housatonic; about Glendale, south of it; and in the Konkapot valley. Its relations to the overlying Berkshire schist are also clear, both from its areal continuity at the north and its structure on both sides of the south end of the small tongue of schist which extends continuously from the West Stockbridge and Lenox mountain mass onto the northeastern flank of Monument mountain.

The Berkshire schist in this tongue and in the schist mass west of it is the usual muscovite (sericite)-chlorite-schist, often graphitic, of northern Berkshire county and Vermont; but along the east and west flanks of the mountains this appears to pass horizontally into or to be overlaid by a very quartzose muscovite-biotite schist with porphyritic feldspars, and resembles the "Buttress type" of the "White gneiss" of Hoosac mountain,[2] which there belongs either below the Stockbridge limestone or represents a transition between the white gneiss and a schist mass which replaces that limestone. A similar schist or gneiss

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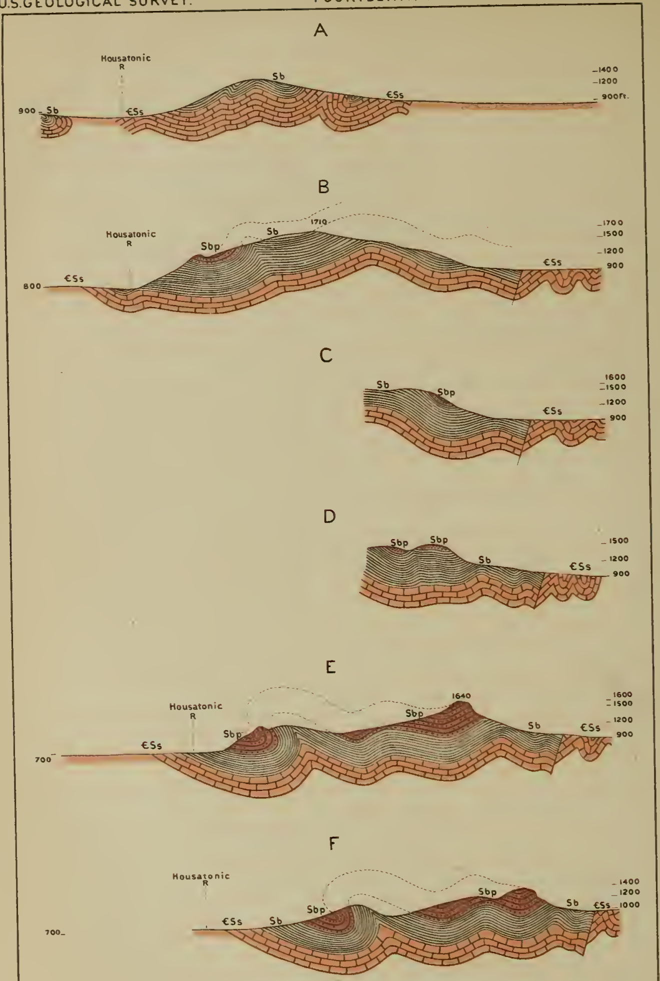
[1] On Taconic Rocks and Stratigraphy; Am Jour Science, Vol. XXXIII, May 1887, pp. 403–408.

[2] See Monograph XXIII, U. S. Geol. Survey, Part II, by J. E. Wolff, p. 54, Pls. VIIa, VIIIa.



MONUMENT MOUNTAIN

Scale $\frac{1}{30000}$: $\frac{1}{25}$ INCH = 100 FT.

occurs also in the Bellowspipe limestone series on Mount Greylock[1] above the Berkshire schist formation, and again on Rattlesnake hill, between Curtisville and Lee, and north of Stockbridge, where it belongs above or below the Stockbridge limestone. The same muscovite-biotite-schist or gneiss constitutes the central part and the summit of the Monument mountain mass, but passes farther south into a very fine grained calcareous muscovite-biotite schist or gneiss, used for and well adapted to building purposes. A similar rock occurs in Great Barrington village, on the east side of Christian hill, and also forms the center of the ridge east of Tom Ball and Long pond. Whatever may be the exact relations of these various schists to each other on Monument mountain, the relations of the muscovite-biotite schists or gneisses to the quartzite are well shown at several contacts.

Three quartzite areas are shown on the map. The rock is a vitreous quartzite, petrographically identical with that which underlies the Stockbridge limestone, as well as that which overlies it in places, and also with that which occurs on Mount Greylock in the Bellowspipe formation, above the Berkshire schist. On the west side of the smallest quartzite area the muscovite-biotite schist dips conformably under the quartzite. In the hook-shaped part of the larger western mass the schists visibly pass under the quartzite, and here a small brook has perforated its way through the schists under the quartzite, coming out on the other side. These relations are shown in Sections C and D, Pl. LXXII. Along the western edge of the eastern mass of quartzite the schists at one point dip visibly under the quartzite, but about 10 feet of ochraceous schist, with minute layers of limonite and some coarse arborescent forms, dendritic or organic, intervene. (Section E, Pl. LXXII.) Along the western edge of the northern part of the western quartzite a small layer of graphitic schist and one or two of limestone occur near the top of the schist. Along the east side and north end of this quartzite mass a more or less thin-bedded feldspathic quartzite is interbedded with an impure limestone. This appears to occur near the top of the schists, and is also characteristic of the Bellowspipe formation.

The rocks of this mountain may be grouped as follows:

Limestone and marble, 1,000–1,400 feet		Stockbridge limestone.
Muscovite (sericite)-chlorite-schists, often graphitic, 300 ft.		Berkshire schist.
Muscovite-biotite-schist, with porphyritic feldspars	500 ft.	Representing either the Cambrian or the Stockbridge limestone (Cambro-Silurian) or the Berkshire schist (Silurian) or the Bellowspipe formation (Silurian).
A similar finer grained but calcareous rock		
An impure limestone		
Quartzite, 500 to 600 feet		Representing either the Cambrian or the upper part of the Stockbridge limestone (Silurian) or the Bellowspipe formation (Silurian).

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[1] See Monograph XXIII, U. S. Geol. Survey, Part III, by T. Nelson Dale, on Mount Greylock, p. 185.

STRUCTURE.

Dana's hypotheses.—Prof. J. D. Dana[1] offers two hypotheses:

(*a*) The mass is an extremely compressed syncline, so completely overturned to the west as to give the strata a very low inclination to the east. (See Fig. 67.) This makes the Stockbridge limestone pass under the mass, and places the schists above the limestone and the quartzite on the west side, and puts both schist and quartzite in the Silurian. It involves the recurrence of the quartzite along the eastern foot between the limestone and the schist and the absence of the schist along the western foot.

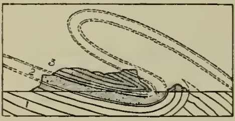

FIG. 67.—Prof. J. D. Dana's hypothesis *a*. 1. Limestone. 2. Quartzite. 3. Gneiss.

(*b*) The mass is an extremely compressed anticline turned over to the west. (See Fig. 68). This places the schists below the quartzite and both below the Stockbridge limestone, i. e., makes them Cambrian. It also involves the recurrence of the quartzite along the eastern foot between the limestone and the schist and the absence of the schist on the west side between the limestone and the quartzite.

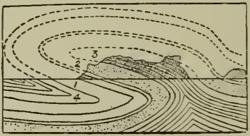

FIG. 68.—Prof. J. D. Dana's hypothesis *b*. 1. Limestone. 2. Quartzite. 3. Gneiss. 4. Schist.

The hypothesis *a* would involve the erosion of twice the thickness of the Stockbridge limestone, 2,000 to 2,800 feet, besides the thickness of the muscovite-biotite-schist, 500 feet, and of the quartzite, 500 to 600 feet, from above the cliffs on the east side. As these are 1,640 feet above sea level, this would make the original altitude of that part of the mass 4,640 to 5,540 feet, from which, however, some deduction should be made for stretching.

Hypothesis *b* would involve the erosion of the thickness of the limestone, 1,000 to 1,400 feet, and of the Berkshire schist, 300 feet, from above the cliffs, making the original altitude of that part from 2,940 to 3,340 feet, with some deduction for stretching.

While the erosion of great loops of rock 1,300 to 3,000 feet thick is quite within scientific possibilities, as shown by modern Alpine geology, it seems safer not to resort to these great loops until simpler theories are shown to be impossible. The chief objection to either of these explanations of Monument mountain lies in the fact of the occurrence of the muscovite-biotite-schist along the western side of the western quartzite and the absence of the quartzite between the limestone and the schist along the eastern foot, although there is a possibility here of its being covered by drift, and this objection has, therefore, not the same weight as the first.

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[1] Loc. cit.

Another theory would explain some of the facts: A fault can be supposed to zigzag from the east to the west, across the north part of the mountain, separating the typical Berkshire schists on the north from the muscovite-biotite-schists on the south. The latter might be regarded as continuous with the similar schists of Cambrian age on the north side of Mount Warner and Mount Keith, near Great Barrington, and the whole mass of Monument mountain conceived as thrust up so as to bring these Cambrian schists in contact with the Berkshire schist (Silurian) coming down from West Stockbridge and Lenox mountains. The quartzite would overlie the muscovite-biotite-schist and, like it, be of Cambrian age. The objection to this theory is that it involves the recurrence of the quartzite along the western as well as along the eastern foot of the mountain, or else the supposition of two longitudinal faults, one on either side, thrusting the limestone down to the level of the schists, neither of which is supported by observation.

Another hypothesis would make the central gneiss mass and the lateral quartzites Cambrian, and the graphitic schists on the north side would then represent argillaceous sediments of the age of the Stockbridge limestone. But the quartzite ought then to pitch under them, which it does not.

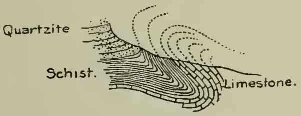

FIG. 69.—Possible structure along east side of Monument mountain.

The structural interpretation shown in Pl. LXXII is advocated on the following grounds: There is a marked parallelism in the features of the mountain (shown on map, Pl. LXXI, and in Fig. 65), the quartzite on the east corresponding to that on the west, pointing to a parallelism of structure. The synclinal structure of the western quartzite appears near its northern end. The presence of an anticline along the east foot of the eastern cliffs is shown by the dips where the road from Muddy brook (Konkapot creek) to Van Densenville crosses the quartzite. A syncline would naturally follow this anticline on the east, and of this there are also indications in the southern part of the eastern quartzite north of this road. (See map and Section F.) The presence of a gentle syncline and of an anticline east of it, both traversing the central schist mass, and the former traversing also the western part of the eastern quartzite, is also shown on the map. (See Sections B and E.) That two synclines with an intervening anticline enter into the structure of the mountain may be inferred from the two schist synclines which project into it from the schist mountain on the north. (See Section A and map.) The maximum amount of erosion from the surface of the mountain involved in the construction here presented does not exceed 800 feet, and this from the central portion, and about 500 feet from the summit, making its original height about 2,300 feet. (See Sections B, E, and F.)

The difficulty of this interpretation arises along the east foot, where the schists on a level with the limestone have an easterly dip, in places a low one, with the limestone a thousand feet east of them dipping vertically (section D). The structure here may be regarded either as a very sharp syncline overturned to the west (see Fig. 69), doubling up all the schists along the eastern foot (and overturned folds are very frequent in western Massachusetts), or else, as shown in the sections, Pl. LXXII, as an ordinary syncline resulting in a normal fault which brought the Berkshire schist down to the level of the Stockbridge limestone by depressing the eastern side of the mountain 400 to 500 feet.[1] The eastern cliffs, now 1640 feet, would have measured about 2200 feet before the faulting. It is quite possible, however, that the quartzite was originally thicker than 500 feet. The drift along the eastern foot prevents nearly all structural observations. That the top of the Stockbridge limestone is represented in the valley east of the mountain is shown by the occurrence of several masses of the overlying Berkshire schist along its center.

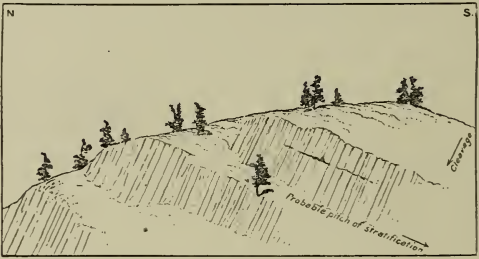

Fig. 70.—The northerly dipping cleavage on the west face of the eastern quartzite of Monument mountain as seen from the west spur.

In further support of this general interpretation comes the fact that on Mount Greylock the Berkshire schist, although measuring 1,000 feet, and even more, in thickness, is overlaid by a mass 600 feet thick of more or less impure limestone, quartzite, calcareous sericite-schist and muscovite-biotite-schist, constituting the Bellowspipe formation, and that the quartzite, calcareous, and noncalcareous muscovite-biotite-schists of Monument mountain correspond to such a series. In the geological coloring of the map, Pl. LXXI, everything but the quartzite and Stockbridge limestone has been thrown into the Berkshire schist formation, owing to the difficulty of defining the boundary between the various schists and the facility of defining the quartzite area. The observed thickness of the sericite-chlorite and graphite schists on Monument mountain is about 300 feet, i. e., 700 feet less than the minimum thickness of the Berkshire schist. All the schists and the quartzite on Monument mountain measure from 1,300 to 1,400 feet. On Greylock the Berkshire schist and Bellowspipe series measure at least 1,600 feet.

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[1] There are some indications of a fracture along the west foot of Beartown mountain, e. g., Ice Glen, in Stockbridge.

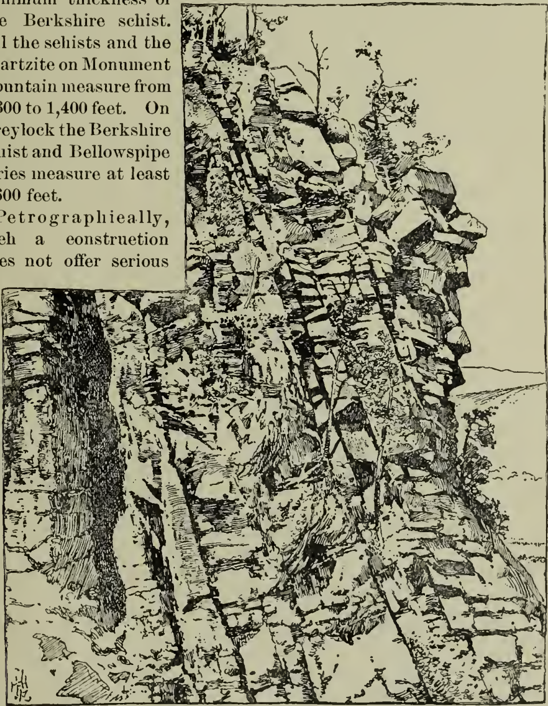

FIG. 71.—Quartzite cliffs, east side of Monument mountain, south face of jog, showing a cleavage dipping north and another dipping east at high angle.

Petrographically, such a construction does not offer serious difficulties. As biotite passes by decomposition into chlorite, the difference between a muscovite-biotite-schist and a muscovite-chlorite-schist is not a radical one. Biotite is also a characteristic mineral of the Berkshire schist of a large area in Dutchess county, New York. But the difference between the two schists on Monument mountain is more probably due to a difference of sedimentation, the muscovite-(sericite)-chlorite-schists originating in more argillaceous sediments and the muscovite-biotite and far more quartzose schists, with porphyritic feldspars, in more siliceous sediments. It is also probable that these schists have been subjected to different amounts of pressure and strain, resulting in different metamorphic processes. The fact that the muscovite-biotite-schists are in places calcareous is also true of the Berkshire schists in western Massachusetts and Vermont, and the interbedding of quartzite and impure limestone is quite characteristic of the Bellowspipe formation.

Cleavage and pitch.—Among the marked features of the quartzite of Monument mountain are its various systems of cleavage or jointing. The more general of these coarse foliations are shown on the map by cleavage symbols. The most conspicuous is that which strikes east-northeast to west-southwest across both the east and west cliffs, and dips either vertically or northerly at a high angle. (See Fig. 70.) Another strikes about north-northwest and dips east at a high angle. (See Fig. 71.) The pressure which in the more pliable schists found relief in minor folds and minute cleavage, produced these sets of fractures in the more coherent and brittle quartzite. In the schist area there is occasionally a southerly dipping cleavage. Sections A and B, taken together, show a marked southerly pitch, the limestone descending with the increasing thickness of the overlying schists, and it is quite possible that the north and south dipping cleavage are related to this southerly pitch and a north to south pressure, while the easterly cleavage is associated with the strike of the folds and an east to west pressure. The southerly pitch of the schists under the quartzite shows itself in the surface features of the east side (see Fig. 72), and the low southerly dipping planes seen in the west face of the eastern quartzite (Fig. 71) are probably due to the pitch of the quartzite.

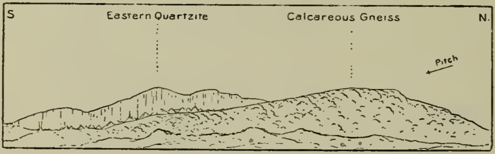

FIG. 72.—The outlines of Monument mountain from the east side of Konkapot valley, showing some of the relations of the gneiss or schist to the quartzite.

The southward termination of several schist masses west of Van Deusenville points to a northerly pitch along that latitude, which may extend far enough east to affect the south end of the Monument mountain mass. The termination of the quartzite outcrops on the south, with their decreasing altitude, would add somewhat to this probability.

STRUCTURAL RÉSUMÉ.

The views advanced in this paper may now be summarized:

Monument mountain is a small synclinorium about 30 miles south-southeast of the center of the Greylock synclinorium and similarly situated with reference to the older gneiss mass on the east. It consists of a series of Silurian beds, quartzite 500 to 600 feet, and various metamorphic schists, 800 feet, resting upon the Cambro-Silurian Stockbridge limestone of the Berkshire and Vermont valleys, and finding their stratigraphic parallels in the series of the Greylock synclinorium. These beds constitute a marked syncline on the west side and another on the east side, corresponding to the quartzite bluffs on either side, with intervening minor folds. The difficult relations between the schist and the limestone along the eastern foot of the mass may be explained either by supposing a fault, by which the eastern side of the mass was depressed about 500 feet, or by supposing a sharp compressed syncline overturned to the west. There is a southerly pitch at the north end of the mass, corresponding to the increasing thickness of the beds, and probably a northerly pitch at its south end.

HISTORICAL GEOLOGY AND RELATIONS OF STRUCTURE TO TOPOGRAPHY.

Monument mountain affords a good illustration of the frequent change of sediment, both vertical and horizontal, which characterizes the geology of a large part of western Massachusetts; arenaceous, calcareous, and argillaceous deposits recurred at relatively short intervals of time and space. The great amount of quartz sand implied in beds of quartzite 500 feet in thickness and the close proximity on the east of a mass of pre-Cambrian gneiss, which may have been above water in Silurian time, fall well together.

The bold quartzite cliffs, which attracted the attention of even the Indian aborigines as well as one American poet, may owe their existence partly to their occurring along the axis of a ruptured fold, but more probably to the steep angle of the cleavage (see Fig. 71), which runs along the strike. The divisional planes which traverse them in numerous directions, and the tendency of the quartzite to conchoidal fracture point to these quartzite masses and to the eroded folds which once connected them as the source of many of the numerous quartzite bowlders scattered over the country to the south; and these planes continue to facilitate further degradation by frost.

1896-97.

GEOLOGY OF THE CAPE COD DISTRICT.

BY

N. S. SHALER.

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GEOLOGY OF THE CAPE COD DISTRICT.

By N. S. Shaler.

INTRODUCTORY NOTE.

It was at first intended that this paper should include the geology of the peninsula of Cape Cod only, but the progress of the work has made it necessary to extend the consideration so as to take some account of the structure and the succession of deposits exhibited in portions of the mainland, as well as on the islands to the southward. The progress of the inquiry has made it necessary to limit the scope of the work to a somewhat extended discussion of the evidence that goes to show the series of geological events which have occurred in this district since the beginning of the Cretaceous period. Such of the facts as pertain to this discussion are given in this paper; further details will be set forth in the geological folios of the area, which it is expected will shortly be ready for the press.[1]

Inquiries in this field have been very limited in their number and range. Those instituted by the United States Geological Survey have resulted in a Report on the Geology of Marthas Vineyard, in the Seventh Annual Report of the Director (for 1885–86); a report on The Geology of Nantucket, being Bulletin No. 53 (1889) of the Survey series (both by the writer of this paper); a report on The Glacial Brick Clays of Rhode Island and southeastern Massachusetts, by N. S. Shaler, J. B. Woodworth, and C. F. Marbut, in Part I of the Seventeenth Annual Report of the Survey (for 1895–96); and the unpublished folios above referred to.

The reader of the above-named published reports and of this paper will perceive that the Cape Cod district has unexpectedly revealed a considerable range of phenomena, the discussion of which is certain to throw much light on the geological history of the Atlantic coast line. Unfortunately the evidence concerning the succession of these phenomena is of a very obscure nature, and it is therefore not surprising that in the reports above referred to some of it was misapprehended and much was not discerned. Nor must it be supposed that in the following pages anything like a final statement of the facts or of the conclusions to be drawn from them is to be found. Such a statement can not be expected until investigation has gone much further.

I take pleasure in acknowledging indebtedness to Mr. J. B. Woodworth for advice in some parts of the work, and to Messrs. Mark S. W. Jefferson and John Gardner for help in obtaining the photographs from which the illustrations are taken.

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[1] Folios of the Geologic Atlas of the United States.

ORIGIN OF CAPE COD PENINSULA.

The origin and structure of the peninsula of Cape Cod have been a matter of passing interest to all who have considered the geology of the southeastern portion of New England. The peculiar spit-like form of this promontory was at first, and naturally, supposed to be accounted for by the action of the marine currents to which are due the construction of so many of the lesser capes along this portion of the Atlantic shore. When it became evident that a large portion of the materials composing the higher parts of the cape had been brought into position by the action of ice during the last Glacial period, the spit theory was abandoned, and it was at once assumed that the greater part of this area owed its existence as dry land to the morainal and stratified drift deposits which are so evident on the surface, the northeastern extremity being a later addition, made by the action of marine waves and currents.

The last-noted hypothesis as to the origin of Cape Cod, by glacial action, long appeared to have much support from the view, so generally entertained, that the outer morainal deposits formed during the advance of the ice were likely to be massive and of great extent; so that it thus seemed reasonable to suppose that the portion of this cape that was evidently not due to marine agencies was accumulated as a frontal moraine. An inspection of this field alone, without the use of corrections which may be obtained from other parts of the country, almost necessarily leads the observer to adopt the view last mentioned. It was not until I had seen much of the morainal deposits of the region between the Cordilleras and the Atlantic shore, and had made a study of the relations of those accumulations to the Tertiary and Cretaceous rocks of Marthas Vineyard, Nantucket, and other parts of the Atlantic coast line between southern New Jersey and Boston Bay, that I gained what seemed to me to be a truer insight into the nature of the singular peninsula of Cape Cod. On this account it appears desirable to preface the study of this district by an account of the facts revealed in neighboring fields which seem to throw light on its problems.

GENERAL RELATIONS OF THE DISTRICT.

A glance at a map of the eastern shore of North America will show that the peninsula of Cape Cod is in some respects the most peculiar feature of this coast line; geographically considered, it is in a high measure exceptional. Its crescentic form, as before remarked, is by no means unique, except as to the great size of the hook, many of the sand spits imitating in a small way the general coastal outline of this peninsula; but in the bold manner in which this salient projects from the shore, in its strong topographical relief, and in the character of its coast line, it finds no parallel, so far as I have been able to ascertain, in any country. This exceptional geographical character naturally leads an observer who is aware of the indicative value of such features to seek the origin of this cape in conditions of an unusual sort, such as will become apparent in a discussion of the general relations of the district.

It has long been known that the Cretaceous and Tertiary deposits so extensively developed in the southern portion of the Atlantic States of this country are continued in an interrupted belt lying to the east of the more ancient rocks as far north as southeastern Massachusetts, the Cretaceous extending up to the deposits on Marthas Vineyard and the Miocene Tertiary reaching to Marshfield, a point some distance north of the northern border of Cape Cod. Associated with these Mesozoic and Cenozoic deposits are extensive series of stratified sands and gravels which have hitherto been commonly classified with the glacial drift. South of New York these beds show little signs of disturbance by orogenic action; such distortions as have been noticed in the beds can apparently in most cases be explained by accidents of deposition. North of New York, on Long Island and in the isles to the eastward, these beds have been subjected to dislocation, which in Marthas Vineyard becomes profound, so far as is indicated by the attitude of the beds, exceeding on the average the distortions of the Appalachian Mountain district or of the neighboring field of the Narragansett Basin.

Certain observers have sought to account for the dislocations of these newer rocks on the New England shore district by supposing them to be due to the action of the glaciers of the last ice epoch. As I have elsewhere noted, this view seems quite inadmissible, for the reason that the uplifting and folding of the beds took place long before the advent of the last ice epoch. As this point is of much importance in the discussion of the problem as to the origin of Cape Cod, it will be well to present the facts in some detail, especially as certain excavations recently made on Marthas Vineyard have somewhat extended our knowledge concerning the history of the glacial work in that field.

On Marthas Vineyard the Cretaceous and Tertiary strata, exhibiting a total section of probably 1,000 feet or more, are cast into folds of considerable amplitude, some of them apparently exceeding 1,500 feet in transverse extent. These folds are compressed, overturned, and faulted; in a word, they exhibit all the marks of mountain-building actions working on stratified deposits of weak resistance to compression and not deeply buried. So general and effective has this dislocation been that it has involved all the rocks which are exposed to view, the average dip of the strata perhaps exceeding 40 degrees.

In these exceedingly disturbed strata river valleys were excavated which had their position determined in the usual manner, the greater streams following in general the strike of the beds, the lesser—those occupied by the temporary streams—running at right angles thereto. The larger of these valleys, that of Tisbury River, is about one-third of a mile wide and more than 100 feet deep. Upon this normal and well-developed topography, which indicates a continuance of stream erosion that must have occupied a period to be measured by tens of thousands of years, came the glacier of the last ice epoch. I have elsewhere[1] noted the fact that this ice sheet had little erosional effect upon the topography of this island, and the impression made by my first studies has been confirmed by recent inquiries in the same field. The facts may be briefly stated as follows:

The ice sheet failed to obliterate many details of the topography which were due to differential erosion before the advent of the glacier. At many points the ridges of harder rock, though at most no firmer than compacted sand or soft clay, stand evidently as they were originally formed. So imperfectly did the ice abrade the surface that the white and red colors of the clays is rarely traceable to a height of a foot above the contact of the till with the underlying beds. Although along the crests of the greater ridges there are morainal accumulations which have in places a thickness of from 20 to 50 feet, these are limited to the northern side of the island; the southern part has only slight moraines. Over nearly one-half the area in which the Cretaceous and Tertiary strata rise above the level of the sea the till coating does not average 3 feet in thickness, and many fields of a hundred acres or more in extent are essentially driftless. On the southern shore the evidence at present afforded by the rapidly retreating cliffs is to the effect that a deeply incised topography formed in the Nashaquitsa clays was not effaced, the sharp valleys being merely filled in with the drift deposits. In a word, the conditions of this area indicate that the glacier of the last ice epoch was of such slight dynamic value that it produced little erosion and that all the important dislocatory work was done long before it came upon the district.

It is to be said that there is some evidence of ice action shown by the character of the latest-formed deposits of the disturbed strata, seen in the presence in one of the conglomerates exhibited at Gay Head of pebbles and bowlders apparently derived from the region of Narragansett Bay, including one fragment of the very characteristic ilmenite from Iron Hill, in the town of Cumberland, Rhode Island. But this ice period of the Pliocene or Pleistocene time was, if it existed, so far as we can discern, an even less effective invasion than that of the last Glacial epoch, and, as it came before the dislocation of the beds, can not possibly be made to account for their disturbance. There is thus no reason to doubt that the extensive stress phenomena of this field must be explained by supposing that they are in some way the result of orogenic action. We are, indeed, justified in assuming that along the section of the shore line extending, it may be, from western Long Island to the island of Nantucket, mountain-building movements involving stresses of considerable intensity have been developed.

As to the operation of these mountain-building actions in the district of Cape Cod, the evidence, though not perfectly clear, leads to the conclusion that they worked on the ill-disclosed foundations of that peninsula in much the same manner that they have done in the well-exhibited beds of Marthas Vineyard. As will be noted in the sequel, the strata which are known on Cape Cod include nothing below the level of the Nashaquitsa series as described in the report on Marthas Vineyard; but the presence of the Tertiary greensands at Marshfield causes the presumption that beds of earlier age lie within the peninsula.

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[1] Report on the geology of Marthas Vineyard; Seventh Ann. Rept. U. S. Geol. Survey. 1885–86 (1888), p. 310.

The limited extent of the exposures of the foundation materials of Cape Cod makes it desirable to take into account the structure and history of the adjacent areas both on the south and on the north. It is, indeed, necessary to do this in order to arrive at an understanding as to the history of the particular area. This consideration should include the origin of the sediments, the nature of the transporting agents which brought them to their sites, the orogenic accidents, the development of the drainage, and the oscillations of the sea level which have taken place on this portion of the shore.

The sediments of the Cretaceous and Tertiary rocks in the district between Washington and Boston exhibit certain peculiarities which are not found elsewhere in the eastern United States. The section is in part made up of colored clays and sands, which, except for the admixture of peaty matter in the lignite beds, are evidently derived from the rapid deposition of land waste washed from an area which had been long subjected to interstitial decay, which was followed by rapid erosion. In the lower portion of the beds the conditions are not so abnormal, the clays and sands in general resembling those of the Southern States. They appear to have been deposited from the discharge into the sea of ordinary rivers. The structure of the lignites, which, so far as observed, contain much clay, indicates that they were formed in an estuarine district, subjected to frequent floodings of muddy water and to slight subsidences, which permitted the peaty accumulations to be buried beneath silt.

In passing to the higher marine strata, we find at once that we are in very different clastic conditions. The beds in the Marthas Vineyard district consist of alternating clays and sands, which have evidently been deposited in a rapid manner. The clays show scarcely a trace of lamination, and the sands are exceedingly coarse, often being made up of bits of decayed granite, the crystals running together in one mass. Much of the deposit is composed of detached, not rounded, crystals of feldspar, which are so far softened by decay that they can be crushed in the fingers. It is, in a word, a true arkose, lacking only the usual consolidation of that material, and so destitute of admixture of such substances as are inevitably brought into detrital beds where the transportation which bore the waste to its resting place was by rivers or shore currents, that a careful study of sections many square yards in area has failed to show a trace of any other material than the broken-up crystalline rock from which it was derived.

After passing up through a section having a total thickness of several hundred feet in which the above-noted alternations are exhibited, we come suddenly to a level where beds of conglomerate, composed of ordinary compound hypogene rocks, occur in pebbles of moderate size not differing much in character from those formed during the last Glacial period, except that they are more decayed and somewhat more waterworn. Yet higher in the section we attain to the Nashaquitsa series, which are also somewhat dislocated. These are beds of sands and clays, in general character like those formed during the last Glacial period, though on account of their greater age they have been much more changed in texture than those of that epoch. The interpretation of this section is difficult. The most probable explanation is that which will now be set forth.

In the first place, we may note the fact that the shore line of the old crystalline district of the Appalachians appears always to have lain near this seat of deposition. The arkose in the Tertiary shows this to have been the case in that period. It was so again at the time of the higher conglomerate, and the character of the clays and arkose beds shows that they were not offshore deposits. The structure of these beds suggests that they were laid down in a swiftly accumulated delta at the mouth of a river, which might well have been a continuation of the Connecticut.

The lower Cretaceous deposits, being in nature such as would be discharged from streams draining a land subjected to ordinary conditions of erosion, demand no special explanation. As before noted, it is quite evident that the rocks beneath the land from which they came had been deeply decayed in a long period of stable conditions, such as has prevailed in the southern Appalachians. Suddenly this zone of decay was to a great extent swept away into the neighboring sea, the process continuing until, as the conglomerates which cap the Tertiary section show, the firm-set undecayed rocks were, in certain places at least, exposed to the eroding agents.

The supposition that there was in the Mesozoic period a deep zone of decayed rock in New England which might have afforded, if subjected to rapid erosion, detritus such as is contained in the clays and arkoses of the Tertiary rocks of southeastern Massachusetts, finds some support in the occurrence at many points in that area, particularly in the southern half thereof, of rocks decayed in place under conditions which clearly show that the disintegration has not been brought about since the last Glacial period. Rocks in this state, exhibiting decay to the depth of some score of feet, occur at various points in and about the Boston Basin, and in a number of places in the Berkshire Hills and elsewhere. A notable instance of this decay of the strata in place was found in the excavation of the Hoosac Tunnel, where, for a length of several hundred feet, near the western portal, the mica-schist was found completely softened at a depth of 400 feet below the surface. Owing to the deep covering of glacial drift which hides so much of the surface of New England, as well as to the fact that the ice of the last ice period removed all projecting rocks of this nature, it is only chance excavations, such as are rarely made, that give one an opportunity to see these remnants of a decay which was once widespread. From a careful examination of the evidence, I am of the opinion that at least one-thirtieth part of the crystalline rocks of Massachusetts, Connecticut, and Rhode Island would, if bared, exhibit decay of the type so well known in the plateau district of the southern Appalachians.

The cause of the sudden removal of this material from its old to its new bed place is not easily determined; the following suggestions seem, however, worth consideration. It is doubtful that the result was brought about by the invasion of the sea during a period of subsidence; the singularly unmixed character of the deposits, the entire absence of marine organic waste, which is likely to be found in beds of this nature, and the perfect assortment into thick layers of like sediments are also against this view. Moreover, the cutting rate of coastal erosion agents is normally slow, while these beds indicate very rapid work of this kind. So, too, the hypothesis of exaggerated land erosion due either to a great increase in rainfall or to a steepening of valleys brought about by a change in the attitude of the land, seems inadmissible for the reason that the detritus from any ordinarily conditioned area would have been stained by the organic waste that all such streams normally bear to the sea. It is difficult to conceive a large river carrying and depositing in succession red and white clays and arkoses without a trace of vegetable detritus.

The difficulty which is encountered in the effort to explain the erosion of the detritus of the Gay Head beds by marine action is well illustrated by what is now taking place on the rapidly wasting cliffs of that part of Marthas Vineyard. The materials of the section are to a certain extent rearranged along the shallow-water belt of the shore, but the various forms of detritus are intermingled, and are mixed with organic matter to such an extent as to make the intervention of the sea unmistakably manifest.

It may be suggested that the beds in question have in some way been bleached or colored since they were deposited. This view can not, as is at once seen, be maintained in the case of the clays, for the lignite beds of the Cretaceous which are mingled with them carry the carbonaceous stain with no trace of bleaching. I have been unable to conceive any chemical action occurring in either the clays or the arkoses which might possibly account for the disappearance of original organic waste.

In this state of the problem I have been forced to bring in the hypothesis that the erosion work which removed the materials of these strata from their parent rocks was effected by glaciation, the ice not attaining to the place of deposition, but delivering the detritus to streams, one or more of which debouched near this part of the coast into the sea, or perhaps at times into a lake. Glacial action accounts for all the facts which we have noted concerning the character of these deposits in a way that no other operation could well do; in fact, without using this hypothesis we are left quite without an explanation of a very interesting series of phenomena.

In favor of the hypothesis that glacial erosion delivered the detritus of the Cretaceous section to the currents which bore it to its present resting place, we may note the fact that occasionally, though rarely, in the clays of the Gay Head cliffs we find large, subangular masses of a yellowish-red sandstone embedded in the strata. One of these, visible for some years, has recently fallen and broken to fragments. It was originally not less than 20 cubic feet in volume. In the course of the thirty-six years that this slowly retreating cliff has been under my observation, five or six of these interesting fragments have been noted which were certainly not to be classed with the ordinary glacial bowlders that often work down the slopes so as to appear as if they were embedded in the strata. It will be observed that these apparently ice-rafted rocks are of sandstone, a material which sometimes resists the process of decay where all ordinary hypogene rocks yield to it. It is just such a petrographical species as we should expect to find affording the rare bowlder which would be formed where glaciation took effect on an area indicated by much decayed crystalline rocks. Thus in the Connecticut Valley, whence these floated masses possibly came, borne by ice rafts, the sandstones have suffered but little interstitial decay, while the older rocks of the neighboring Berkshire Hills have, as noted, been in places much disintegrated.

The orogenic history of the Cretaceous and Tertiary strata of the New England islands is even more puzzling than are the conditions of their formation. So far, no evidence has been adduced to show the action of mountain-building forces in any of the beds of this age in the region south of New York. To find on this portion of the coast much evidence of dislocation of a high order is surprising; it justifies, indeed, the effort of those geologists who have endeavored to account for these movements by the thrusting of the ice sheet. We have seen that this explanation is for several reasons inadmissible, and the question arises as to the origin of the compressive strains which have acted in this area. To determine this, so far as it is at present determinable, we should begin by noting the following facts:

The amount of the shortening of the beds as shown on Marthas Vineyard, where a cross section having a length of about 5 miles is exposed, is probably nearly 2 miles. This is shown by the fact that the average dip of the beds, as determined by many observations, is about 45 degrees. There is good reason to believe that the area involved in these disturbances is much greater than the exposures on the island seem to indicate. In my opinion the beds may reasonably be supposed to have at least twice the extension across the strike that is known to exist, and it is not improbable that the area involved may have a width of 30 miles. The dislocations on Nantucket, though not well known, and those noted by Mr. Woodworth on Block Island, and also those on Cape Cod, hereafter to be described, seem in a way to validate this conjecture.

We have next to note that while the strikes of the folds on Marthas Vineyard are somewhat irregular, their commonest direction is from north-northwest to south-southeast, or nearly at right angles to those of the Appalachian folds of the neighboring mainland. This feature at first raised a doubt as to the orogenic nature of these foldings, for the reason that it seemed unlikely that such a departure from the normal strike of the district would take place if the movements were in character like those ordinarily involved in mountain building. But a comparison of the facts with those observed in other areas makes it clear that this discrepancy is not of great significance. In the Cordilleras and elsewhere it is not uncommon to find that the later movements in any mountain system show the effect of stresses acting at high angles, or even normal, to those which were originally effective. It seems, indeed, that the compressive strains of any district tend in the course of time to satisfy themselves through folds running in more than one direction; that when the strains in a certain axis are relieved there is often a tendency to form others in contrasted directions rather than to develop those which were first made. Therefore, the peculiar position of the axes of Tertiary disruption in this area can not be urged as a weighty argument against their true orogenic character.

It is to be observed that the dislocations of the Marthas Vineyard and Cape Cod sections differ in a notable way from those which occur in the older rocks of the Appalachian district. The folds are small, none of them, so far as clearly observed, exceeding a few hundred feet in horizontal amplitude; they are much compressed, and frequently overturned; they are cut by numerous faults, none of which appear to have a throw of more than 100 feet. In some places these accidents of stressing are so numerous and have so intermingled their effects that the result is a confused jumble of entangled beds which can not well be unraveled. At first sight these peculiarities of movements of the Marthas Vineyard section suggest to anyone familiar with ordinary mountain-building work that the strains which have effected them were of a different order from those which uplifted the Alleghenies and other normally folded mountains. It is, however, to be noted that the stresses which acted on these newer rocks took effect under very different conditions from those under which the old strata of the Appalachians were dislocated. There the beds were rigid and deeply buried; here they were soft and had little overburden to oppose their movements when the stress was applied to them.

As yet we have little information concerning the nature of the work done by orogenic action in the superficial portions of a section on which it has taken effect, but all the considerations derived from laboratory experiments, as well as from the principles of dynamic action, lead us to believe that near the surface of a stressed area the folds are more likely to be small and of varied form than in the deeper-lying parts of it, and that in soft strata without beds of such rigidity as to control the movements slight local accidents are likely to determine the formation of many small folds rather than a few of large size.

It is worth while here to note that these Vineyard dislocations, in case they are accepted as of truly orogenic nature, may well be taken as examples of what is likely to be the type of mountain folding as exhibited in weak beds which, at the time of disturbance, lie within a few hundred feet of the surface. So far as I am aware, there is no better place known in which to study this interesting phase of mountain building.

Assuming, then, that the rocks of the sections exhibited on Marthas Vineyard owe their very great dislocation to forces which had their origin in the under earth, I shall consider certain possibilities as to the exact source of these strains. It may be suggested that a slipping movement has occurred in these beds, due to the formation of a great inclined fault extending parallel to the shore and dipping toward the sea at a high angle, the resulting movement being in effect a landslide. This view is inadmissible for the reasons that there is no trace of such a slip fault; that the section moved is of a rank in size of which we have no knowledge elsewhere; that the transverse shortening of the beds is too great to be accounted for in this manner, and that the direction of the axes of the folds is at about right angles to such as would be formed in such a movement.

It may be worth while to set forth another hypothesis which I have been led to apply to these movements in order to arrive at an explanation of them without recourse to true mountain-building action. This is as follows: A large part of the materials in the Marthas Vineyard section is feldspar, which had apparently been imperfectly kaolinized before it was brought to its present site. Is it not possible that the considerable increase of bulk attendant on this conversion of feldspathic matter into kaolin may have led to internal pressures? It appears, however, that of the mass not over 15 per cent can be reckoned as feldspathic, while even if the whole of it were of that nature and all the changes had come about since the beds were laid down the amount of enlargement would be too small to account for the observed disruption of the beds.

It seems evident that we must account for the folding and other movements of the Tertiary and Cretaceous rocks of these New England islands by the ordinary process of mountain building. Questions then arise concerning the nature of the dislocations by which the compressive strains were applied to these superficial beds. The general slope of the hypogene and Carboniferous rocks on the neighboring faults has apparently taken place in a basin without a border of harder rocks on either side through which the compression strains might have been carried. It seems likely that the contraction of the basement beds, however great, would have failed effectively to compress a thick mantle of soft material unless it had been in a basin. The natural result, if the beds lay on a sloping floor without a rim, would appear to be a mere slipping of the bed rocks upon the softer materials, without any such folding as we find. There are obviously no marks of a basin structure made up of the older rocks in the district where these disturbed beds lie. It is possible, however, though there is no evidence whatever to support the suggestion, that there may be a rim of such older rocks lying below the level of the sea.

There is, as is generally admitted, good reason to believe that this portion of the continent stood, in the period extending from the close of the Trias to the beginning of the Cretaceous, at a much higher level than it does at present. During that time a broad river basin may have been excavated in which the Marthas Vineyard Cretaceous and Tertiary were laid down. I have elsewhere called attention to the fact that the Carboniferous beds of the Narragansett district and other local accumulations along the Atlantic coast appear to have been formed in drowned river valleys, and that the beds have since been subjected to mountain-building actions, the trends of the resulting folds having often departed widely from the trend of the neighboring axis of the Appalachian system. I am disposed to think that the Tertiary and Cretaceous beds of Marthas Vineyard have had the same general history, but the fact must be recognized that the evidence to support the conclusion is defective. All that can be said in its favor is that it is consistent with the basin-like origin and structure and the nature of the folding which characterize the localized mountain-built areas of the Atlantic coast.

We now come to the subject of the erosion phenomena of this district, and here we find ourselves in an interesting but difficult field. Beginning with the island of Marthas Vineyard—Capawok, as the Indian name has it—a district which gives us the most information concerning the structure and history of the field, we find there good evidence that the Tertiary and Cretaceous rocks have been subjected to a great amount of erosion since they were dislocated. On the western half of that island these beds rise to a height of about 300 feet above the present level of the sea. As there is an area of about 30 square miles where the crests of the divides have about the same elevation, there is good reason to believe that the existing topography was carved from a surface which, by base-leveling, or more likely by marine erosion, had been brought to an approximate level before the last Glacial period. If I am correct in supposing that there had been a tolerably complete base-leveling or benching with reference to a sea level above the tops of the present divides, then the development of the mainland makes it eminently probable that these old deposits underlie the newer beds at a depth of not more than 1,000 or 2,000 feet below the surface of the sea. How, then, were these lower beds affected in order that they might transmit the strain to the Mesozoic and Cenozoic deposits? and what, if any, were the dislocations on the mainland that were produced at the same time? It seems to me that neither of these questions is, in the present state of the inquiry, answerable with any measure of affirmation, but some suggestions may be made which are perhaps not without value.

As to the movements of the rocks, presumably crystalline, that constitute the foundation of the Marthas Vineyard section, the conditions are substantially the same as those which have existed beneath the Carboniferous deposits of the Narragansett Basin. When they came to be folded, with a measure of compression quite like that which has affected the beds with which we are now concerned, as we may see when the folded Carboniferous beds have been stripped away from the hypogene rocks, the yielding of the crystallines appears to have been made mainly by the interstitial movements of those rocks, and not to any great extent by faulting. All the evidence we have goes to show that while ordinarily massive crystalline rocks may be folded, as is sometimes indicated by the dikes they contain, a frequent method of accommodating themselves to pressure is by squeezing. This action is, indeed, common enough in all rocks which have been subjected to compression strains, as is shown in the distortion of fossils. The absence of any distinct indication of recent faulting on the mainland near Marthas Vineyard affords some support to the supposition that the giving way of these basement rocks was rather more by interstitial movement than by dislocation.

It should also be said that the peculiar position of the masses of decayed crystalline rocks which, as above noted, occur in the three more southern States of New England, long ago led me to the supposition that, after this decay had been effected, a certain amount of faulting occurred, which lowered wedges of the disintegrated rock down to levels to which the surface actions had not penetrated. Moreover, efforts which I have made to account for the details of the topography at several points in southern New England have led me, quite independent of the problems of the Tertiary dislocations, to the idea that at a time not long before the last Glacial epoch there was a certain amount of disruption by faulting in that part of the mainland. This problem of recent faulting on the mainland needs more study than I have been able to give to it; the matter is only suggested here to show that there may be more extensive evidence of orogenic action on this part of the continent than has hitherto been supposed.

A part of the difficulty connected with the question as to the nature of the movements involved in the dislocation of the Marthas Vineyard section arises from the fact that the development of these folds and of the Gay Head Tertiary beds. There are no good exposures, but enough is shown to make it clear that the Tertiary portion of that section is above the level of the sea along this line of islands. This condition of a sheet of moraine capping a divide is seen also on Marthas Vineyard, where the broader valleys are in their lower parts almost driftless, while the crests of the ridges are usually crowned by a layer of morainal materials having a depth of from a few feet up to about a hundred feet. This feature goes to show that deposits of this nature tended to accumulate on the high ground. We shall have occasion to examine this matter more closely when we are considering the distribution of the moraines in the Cape Cod peninsula.

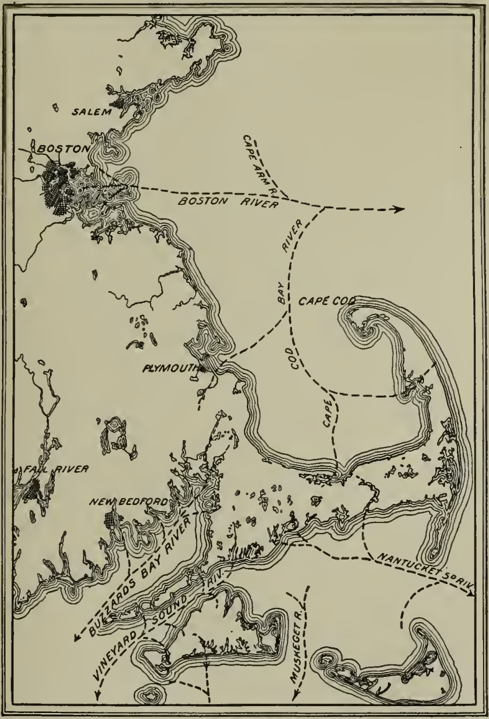

FIG. 86.—Sketch map showing the probable position of the streams of the Cape Cod district during the period of elevation preceding the last Glacial epoch.

present topography began long after the close of the mountain-building work.

The pre-Glacial topography of Marthas Vineyard has been but little disturbed either by glacial erosion or by the resulting drift coating. We can see that the course of the principal brooks—rivers, as they are locally termed—has been determined in general by the strikes of the beds coinciding therewith, while the smaller water courses cut across the folds in a normal way. The beds being all of slight hardness, the topography is smooth, but here we find sharp and continuous ridges which owe their relief altogether to differential erosion. These serve to show us how slight has been the wearing effected by the glaciers of the last ice epoch. The absence of such ridges on the remnants of the ancient upland plain also indicates that this plain was due to some action which wore it to a tolerably perfect level.

So well has the pre-Glacial topography of this island been preserved through the accidents of glacial invasion, that we can not only trace two or three cases of ancient stream robbery, but a close inspection makes it evident that all of the brooks of considerable size follow at the present time the channels they had before the ice came. In only two cases have I found that the morainal or other accumulations have changed in an important way the course of the waters. I note these points in order to show that the evidence from these streams as to the general drainage of the district is of value.

Taking the distribution of the brooks of Marthas Vineyard, we note that they are divisible into two groups—those which, turning south, fall into the broad ocean, and those which, descending from the northern side of the island, enter Vineyard Sound. The first-named group of brooks gives us little information except that they enter the sea through what appear to be drowned valleys, and are therefore evidence that the level of this land has been materially lowered since the existing topography was formed. The streams of the northern shore exhibit even more distinctly the same feature of drowning at the mouths, though this is marked, not by their entrance into lagoons, but by the filling of their channels near the sea level by moving sands. On this northern shore also we find in the distribution of the brooks the suggestion that when the land was at the level at which the river topography of the district was developed they entered a large stream occupying the central part of the broad valley now covered by Vineyard Sound.

The general structure of Vineyard Sound is easily misconceived. It has been suggested by Mr. Clarence King that the long range of the Elizabeth Islands, which form the northwestern boundary of this water body, is essentially morainal. There is undoubtedly a covering of morainal drift on the top of these islands, but on examination they prove to be composed mainly of beds similar to if not contemporaneous with the Nashaquitsa section. They probably contain also some part

The fact that the Elizabeth Islands are not essentially morainal greatly increases the probability that the valley of Vineyard Sound was excavated by river action. The stream which occupied it during the period of elevation, when the erosive work was done, appears to have had its source on the southern side of Cape Cod. On the west of the Elizabeth divide, in the valley of Buzzards Bay, there was, if this conception of the history of the district be correct, another river which headed in the region about Wareham, taking about half its drainage from the district underlain by the ancient rocks of the mainland. In both these valleys we find the general features of drowned valleys exhibited quite as they are shown in the more southern bays of the Atlantic coast. The basins slope to the seaward, but not in a perfectly regular manner, for the reason that they are much encumbered by drift accumulations and by the waste that has been rearranged by the strong tidal currents which sweep through the bays and sounds of this district. They both widen to the seaward, as we should expect them to do if they had been excavated by the action of land waters.

The position of a third stream is perhaps traceable on the Muskeget Channel, which separates Marthas Vineyard from Nantucket. This headed against Cape Cod and against the upper tributaries of the Vineyard River, as we may call the stream which occupied the sound of that name. It is likely that to the inosculation of these headwaters we owe the formation of the channel which now separates the islands last mentioned from the peninsula of Cape Cod. In the sketch, fig. 86, the conception of the drainage of this district as it was before the last great upward movement of the sea is indicated. In such a figure it is inevitable that many features which are highly conjectural should be shown along with those which are well supported by evidence. In this case the doubt which is the most serious attaches to all that relates to the channels between the eastern end of Marthas Vineyard and the western side of Nantucket and between the last-named island and the mainland. As the tidal currents which flow through this water way are strong, some part of the erosion may have occurred both before and after the last Glacial period, at those stages of elevation and subsidence when the sea was free to pass through these channels. There is also a question as to the nature of the submarine ridges which so abound in these waters.

As regards the shoals of Vineyard and Nantucket sounds, it may be said that some of them, particularly those in the eastern portion of the last-named sound, are of moving sands, and, therefore, may have no relation to the continental topography. Some of these submerged ridges are more reasonably to be considered as preexisting, though their shapes may have been modified by tidal currents. Thus the long shoal, known as the "Middle Ground," which extends along the north shore of Marthas Vineyard from near the west chop of Holmes Hole halfway or more toward Gay Head is, as we may judge from the soundings, a bit of submerged land topography. Although it is now the line of a strong division of tidal currents, and is consequently the seat of a "rip," this perturbation in the movement of the water appears most likely to be the consequence and not the cause of the elevation. So, too, in the case of the shoals to the northward and eastward as far as near Monomoy, there is nothing in the tidal movements which are competent to produce them, though the resistance which they offer to the movement of the currents has doubtless served to effect changes in their forms. If the statements of those fishermen and pilots who know these waters well may be trusted, these submerged ridges often contain on their surface considerable bowlders, which, if true, indicates that they are not in most cases the products of current action, but were formed mainly by subaerial agents of erosion.

It is to be noted that the channels south of Cape Cod to the west of Monomoy Point have in general a definite topography, characterized by steep slopes from the neighboring shores. This form of bottom seems to me inconsistent with the supposition that any great amount of sand is in the possession of the currents along these depressions. It is also noticeable that there is little trace of shifting sands along the shores on either side of Vineyard Sound. Furthermore, it is to be remarked that these valleys, as is shown by the protraction seaward of their very definite land slopes, have not been cut back on the average more than from 500 to 1,000 feet since the shore came to occupy its present level. All these considerations lead me to believe that the floor of these basins is not occupied to any great extent by drifting sands. For the reasons given above, the shoals to the east of Monomoy have been in general regarded as evidence of minor divides formed in the great submerged valleys.

The oscillations of sea level in this region have been more than once referred to in the preceding pages of this report. We have now to review the evidence, with a view to formulating it in a definite manner. It should be noted that there is in this district little, if anything, in the way of ancient beaches to afford data as to the altitude of the land in the periods which are under consideration.

On the mainland to the northwest of this region there are evidences of a base-level of river erosion or of marine planation, which Professor Davis and others regard as of Cretaceous age. The portion of this level at about 400 feet above the present shore line possibly corresponds with the present summit of the Cretaceous deposits of this island nearly enough to warrant the supposition that the sea stood at a height of some 400 to 600 feet above its present position when the lower Cretaceous of Marthas Vineyard was laid down. It should, however, be noted that those beds, owing to their dislocation by mountain-building action, may have been moved either above or below the general plane on which they were deposited.

It is evident that the lignitic portion of the Cretaceous beds was laid down rather above than below the sea level, while the deposits containing marine fossils were formed below the plane of the sea. There is thus evidence of shore swaying in this portion of the section. As yet it has not been clearly determined which of these two elements of the Cretaceous lies the higher. The facts show, however, that in this part of the formation the shore was near its present level, and that it was instable.

Between the lower Cretaceous and the middle Tertiary there is a great blank, which includes the uppermost Cretaceous and the Eocene. As yet, the much-disturbed condition of all the beds showing the contacts of those horizons makes it impossible to say what measure of unconformity existed between them when they were laid down. It seems probable, however, that no mountain-building action had taken place in the district during this interval.

It is not yet perfectly certain that the middle Tertiary strata of this district were deposited in salt water. The marine fossils contained in the beds are found under conditions that admit of the supposition that they were not living when the strata were formed, but were swept in from previously existing deposits. I am forced to regard the determination of the age of this section as in some measure uncertain, but it is clear that it is newer than the Eocene and older than the Pleistocene. The general nature of the beds is most consistent with the supposition that they were formed in an estuary. Assuming that they were made at or about sea level, we should have to conclude that there had been no great change in the position of the shore line between the lower Cretaceous and the Miocene periods, or, what is more likely, that there had been a return of the seashore to about its same altitude in relation to the land after whatever oscillations it had undergone in this long interval.

In the Pliocene, as is shown by the fossils contained in the small locality, now destroyed, at the top of the Gay Head cliff, it is evident that, for a time at least, a shallow sea lay over the surface of the Tertiary beds, which were still in their horizontal position, for these Pliocene beds were evidently involved in the mountain-building movements. It can not be inferred that the altitude of these fossil-bearing Pliocene beds above the sea (about 100 feet) is evidence of a general upward movement of the shore, for the reason that the change of level may have been due to the folding of the strata.

The deposits of the Nashaquitsa series apparently indicate the existence of the shore line at least 100 feet below its present altitude. These beds may be regarded as closing the Pliocene record, and as formed, in part at least, before the orogenic movements took place.

After the series of constructive processes above noted had been accomplished, the beds of this district appear to have been established at a level some 200 or 300 feet lower in relation to the sea level than their present position. During the time in which they occupied this inferior level the upper base-level or bench of Marthas Vineyard probably was formed. It may, in passing, be remarked that the general topography of the bottom of the sea, from the southern end of Nantucket Shoals to Nova Scotia, is in favor of the supposition that we have in this district a surface that preserves in a general way the contours impressed upon it by subaerial erosion.

The down-sinking of this region some time during the Glacial period probably brought about the drowning of the great valleys. It evidently resulted in a lowering of the land at least 100 feet below its present altitude, as is shown by the fact that the morainal aprons or sand plains which are so conspicuous a feature in Marthas Vineyard, Nantucket, and Cape Cod attain about that altitude. These aprons are, as elsewhere noted, composed of sand and gravel, with occasional bowlders of considerable size, which evidently attained their present sites by ice rafting. They have, however, a characteristic submarine topography, such as could not well have been made by any form of subaerial action. The "scour ways" noted in the report on Marthas Vineyard[1] as existing on these aprons are of themselves sufficient to establish the presence of the sea over these plains.

As yet there is no evidence concerning the upper limit of this submergence, which occurred in and possibly before Glacial time. After a careful search throughout southeastern New England, the shore line of the sea in the time when the morainal aprons were formed has not been found. Here and there, at the height of about 200 feet, there are what may be faint traces of a coastal shelf, but they are too indefinite to afford any clear evidence of such a line. The distribution of the drift in the southern part of Marthas Vineyard, in the towns of North Tisbury and Chilmark, is such as to suggest that the glacier did not, save in certain small tongue-like projections, extend south of Tisbury River, and that the drift south of that stream was all rafted to its present site. If this view be confirmed by closer study of the deposits, it will affirm the hypothesis that the whole of the island was under water, for the materials which appear to have been thus transported are found on the very highest land, at an elevation of 300 feet above the sea.

I have elsewhere[2] endeavored to show that on the southern face of the hills of Mount Desert, Maine, we have good evidence of a depression at the close of the Glacial epoch amounting to at least 1,100 feet, and possibly extending up to the highest summits, or 1,527 feet. It seems likely that a depression of even the lower of those levels on the coast of Maine would have involved a submergence in the region of Cape Cod sufficient to have covered the highest lands in that vicinity. It thus appears probable that the Glacial submergence of this district carried the whole of its area below the level of the sea.

The emergence of the Cape Cod district from the Glacial depression must have been very rapid, for the surface appears substantially as it was left by the ice. The delicately molded topography of the drift has not been effaced by wave action, nor, as before remarked, are there any traces of ancient beaches. At first sight this absence of any effect of the waves on the surface seemed to me clear evidence that the area could not have been under water since the disappearance of the glacier. In order to determine this point, I visited the region below the elevated beaches in central New York, and found there the same unaffected conditions of surface which exist in southeastern Massachusetts. The conditions of submergence and emergence must have been approximately the same in both areas. It appears, therefore, that we have to accept the conclusion that the uprising of the land after the Glacial period was so sudden that the waves and shore currents did not have time to do effective work. It is possible, however, that the waters were at this time so far obstructed by floating ice that no great amount of wave action took place during a considerable length of time in which the elevation was going on. The last change of level of the Cape Cod district evidently brought the land somewhat above the plane at which it at present stands. This is shown by the occurrence at various points of submerged forests, as in Nantucket,[1] and in the marshes bordering the harbor of Holmes Hole, Marthas Vineyard. The amount of this recent downward motion is not known, but it may have been sufficient to obliterate the land connection which united the islands of Marthas Vineyard and Nantucket with the mainland. The reason for supposing a connection between these islands and the mainland is found in the substantial identity of their faunas and floras with those which exist on the neighboring continent. Considering the width and current-swept nature of the sounds which separate those islands from the mainland, it appears unreasonable to suppose that all these species of animals and plants could have found their way to the outlying stations in the short time which has elapsed since the Glacial period. The conditions of passage are almost as difficult as they are at the straits between the islands of Bali and Lombok, which separate the biological provinces of Australia and southern Asia. As there has been a subsidence since the forests regained possession of these islands, it is reasonable to suppose that the previous elevation was great enough to bring about a connection with the mainland.

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[1] See Seventh Ann. Rept. U. S. Geol. Survey, 1885–86, p. 316.

[2] See Eighth Ann. Rept. U. S. Geol. Survey, 1886–87, p. 1009 et seq.

It is to be noted that the changes in the relative elevation of sea and land have all been spoken of as if they were due to changes in the altitude of the land. It should be observed that this assumption is incorrect. There are at least two main and efficient causes of alteration in the position of the sea in relation to the land, as well as many others of minor importance which probably have some value. One of these, local in its nature, is the swaying of the land against which the sea lies; the other is change in the form of the sea bottom affecting the height of the open waters along all the shore. It is rarely possible to differentiate these causes. In the case of the Iroquois beaches in central New

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[1] See Bull. U. S. Geol. Survey No. 53, p. 28.

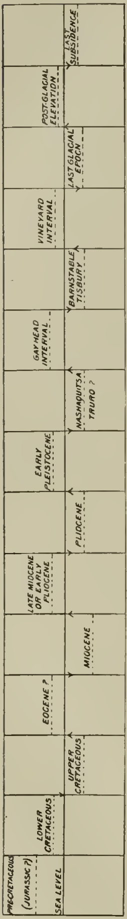

FIG. 87.—Diagram showing the probable movements of the Cape Cod district since the Jurassic period.

York, the fact that they rise to the north supplies a criterion, the like of which may be found in other places, which indicates that the post-Glacial elevation was due to a land movement. Again, as I have elsewhere endeavored to show,[1] the very general drowning of the lower valleys of the rivers of all the continents affords evidence that there has been, in very modern times, a general rise of the sea level to the amount of 100 feet or more. It is to this general inundation that we may perhaps attribute the destruction of the land bridge which for a long time after the close of the Glacial period united the New England islands with the mainland.

There is some evidence as to the duration of this land bridge to be derived from the possible rate of marching of the oaks and other heavy-seeded trees northward from their southern refuge during the last ice time. These trees, in the process of repossessing an abandoned field, do not, according to my observations, advance at an average rate of more than 5 feet a year. To assume a rate of 10 feet a year would be to allow the utmost that could be supposed. This would require about 500 years for a mile of journey, or about 2,000 years for the passage across a land bridge from the mainland to the island of Marthas Vineyard. I have elsewhere urged this slow rate of northward march of the heavy-seeded trees as an argument against the hypothesis that the close of the glacial advance, when the ice lay at the southernmost point it had attained, was not more than from 10,000 to 20,000 years ago. If the argument be valid, the return of the oaks to southern New England, after their expulsion to regions farther south, must have required somewhere near 200,000 years.

It is possible that some of the topographic features of the submerged channels of this area are due to the erosion which took place during the elevation that followed the Glacial period. The cutting away of the divide between what we have supposed to be the drainage basins of the Vineyard and the Muskeget rivers may have been in part effected by the energy of the tidal currents, which, in case the passage were diminished in sectional area, would act with something of the strength they now have in passing from Vineyard Sound to Buzzards Bay through the shallow passage known as Woods Hole.

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[1] See Bull. Geol. Soc. Am., 1895, p. 153 et seq.

We have next to consider the erosion performed in this district by the ice of the Glacial epoch. It is now well known that the original conceptions as to the amount of this wearing on the general surface of the country were very much exaggerated. There are few students of the phenomena in the field who would be disposed to believe that the average of this erosion in New England amounted to as much as 100 feet. I doubt whether it was as much as 50 feet. It has commonly been supposed, however, that in incoherent materials the action was more effective than in firm-set, highly changed rocks. So far as we can judge from the conditions seen on Marthas Vineyard, where the contact of the drift with the underlying sands and clays is well revealed by the cliff sections and the clay pits, the glacier did little more than smooth over the soft materials without effacing their original outlines. In no case is any considerable amount of the characteristically colored clays and sands mingled with the till covering. It is usually impossible to find a trace of them at a height of 2 feet above bed rock. When we consider that this occurs at points where the ice has journeyed for a mile or more over the soft beds the absence of all marks of erosion is seen to be very remarkable.

I have already noted the fact that the glacier failed to destroy even the minor features of the topography of this field. It is difficult to exaggerate the extent to which the pre-Glacial topography survives in the Vineyard area. The facts must indeed be seen, and this carefully, to be appreciated. There is one way, however, in which the glacial conditions effected a considerable amount of local erosion in this district. This was by the action of the subglacial streams which flowed upon the surface of the bed rocks. All along the northern face of Marthas Vineyard we may trace these subglacial river ways, which extend from the shore in winding, sometimes beautifully curved, channels cut down into the soft rocks to where they discharged beyond the front of the ice. Sometimes these channels are coincident with earlier-formed valleys. Again they are carved where it is evident that open-air streams have never flowed. The largest, and in some ways the best, example of these interesting and elsewhere unnoted features is seen at Chappaquonset or Tashmu Pond and in the valley which continues the depression to the southward. As elsewhere noted, these grooves, extending from the shores of Vineyard Sound upward, terminate on the south in the morainal apron, or, rather, are continued over that apron in other shallower and wider troughs cut in the sands which extend downward to the ocean shore. In some cases the bottoms of the grooves which were under the ice have been worn down to the depth of 60 feet or more into the soft bed rocks.

It is likely that the low places in the Elizabeth Islands divide, as at Woods Hole, Quicks Hole, and Robinsons Hole, as well as certain others which do not go below the level of the sea, are due to a like action of subglacial streams when they crossed the ridge lying between the sound and the bay. Similar valleys will be noted in the detailed account of the structure and topography of Cape Cod.

We have last to consider the extent of the post-Glacial marine erosion which has occurred in this district. This has been and is still great; at present it is some hundredfold greater than that done by land waters, but the distribution has been in certain regards peculiar. As before noted, the marine benching of this district which occurred after the deposition of the Pliocene strata was apparently pushed to the point where the whole area of the Cretaceous and Tertiary rocks was brought to a level. This may possibly have been due to base-leveling by stream action, but whoever will observe the practical absence of such work on the strong topography of Marthas Vineyard, where the brooks are never colored by the soil waste and where there is not a single stream scar, will hesitate to hypothesize this slow process of lowering to a common level such rocks as here occur. There are on Marthas Vineyard pretty clear evidences of the existence of a second level of marine benching at the height of about 150 feet above the sea. This bench is recognizable around nearly the whole of the western elevated section of the island, and as there is no structural basis for it it must be regarded as of marine origin. Its original width can not now be determined with accuracy, for it is much diminished by marine erosion, but on the average it can not well have been less than one-third of a mile, and may have been more than twice as great as that amount. Thus the pre-Glacial erosion due to the sea apparently includes two large operations, the formation of the original level surface of the island and the cutting of the lower bench, which was a much less extensive work. As to the benching which may have been done in the sections below the water level, the evidence, though in a way interesting, is too perplexing to warrant discussion.

The post-Glacial marine erosion of this district has been extensive and is now in process of very rapid development; no other portion of the coast of North America is undergoing such a complicated and rapid readjustment. When the problems which are there presented concerning the action of the sea on the shore and the arrangement of the detritus derived from the process of erosion are worked out, this area will become the classic ground for students of coastal action. For our purpose it will be well to divide the question into two heads, the first relating to the amount of erosion already done, the second concerning the manner in which the work is effected.

In this, as in most other shore lands, the only possible way of determining the extent to which the sea has gained on the land is to take the slopes which extend downward to the sea and ascertain where, if protracted, they would cut the water level. This method is particularly applicable on shores such as those of southeastern New England, where there is a gentle slope toward the sea. On this basis, using for data observations made at some scores of points, I have come to the conclusion that if the land had been stable since the last ice time the average retreat of the shores might safely be estimated at rather more than about one-half a mile. Unfortunately for the sufficiency of this method, it is certain that there has been a subsidence, which may be, and most likely is, now going on, so that the resulting work of the sea is not the formation of a horizontal shelf but of a sloping scarf, much of which is submerged. Thus we can only say that, the rate of the down-sinking being unknown, we are deprived of any means of accurately fixing the extent of the incutting since Glacial time, and are driven to the ruder method of noting the amount of recession of particular cliffs.

Turning to the evidence afforded by the cliffs, the best obtained is that due to the surveys of the late Prof. H. L. Whiting, long the senior assistant of the United States Coast and Geodetic Survey, who fixed the rate of erosion of the Nashaquitsa cliffs by very careful observation for a period of fifty years at 3 feet per annum.[1] The evidence is clear that this is the rate for nearly if not quite the whole southern shore of Marthas Vineyard. At Gay Head there are only approximate data, which serve to show that most likely the retreat does not amount to as much as a foot per annum. Along the north shore of Marthas Vineyard the process of erosion is very slow, save at a few salient points west of the steamboat landing. At West Chop the rate does not average a foot in five years, but at the east and west chops of Holmes Hole the cliffs have for some years been retreating at an average rate of at least 2 feet per annum. This wearing is probably in some way connected with slight alterations of the shoals which direct the tidal currents against the shore. On the Cottage City or eastern face of the island the rate of wasting is also great. The recession of the shore has amounted to at least 30 feet in fifteen years, and this despite some slight efforts made to resist the action of the waves. The region near Edgartown is amply protected on its east side by the extensive system of hooks about Cape Pogue. As a whole the shores of Marthas Vineyard in process of erosion, excluding the island of Chappaquiddick and the Cape Pogue hooks, are probably entering the land at an average rate of about a foot a year. The mean height of the sea-cliff face may safely be taken at 30 feet, and the total face subjected to erosion at 35 miles. This would make the quantity of material removed amount to a total of about 1,000,000 cubic feet per annum.

On the island of Nantucket, owing to the extent of the sand-barrier beaches, the proportion of the total shore line which is exposed to active erosion is less than that of Marthas Vineyard, but the wearing action of the sea is much more effective, for the reason that clays rarely appear in the escarpments, which are mostly of stratified drift, such as is found in the morainal aprons. The southern shore of the island and a portion of its northeastern face are apparently retreating at the rate of more than 4 feet per annum. Yet, for the reason above given, it seems likely that the average encroachment of the sea is much less rapid than it is in the island of Marthas Vineyard.

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[1] Geology of Marthas Vineyard: Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 361.

The Elizabeth Islands are wasting for the greater part of their length, but the process is now being arrested by a simple action which has brought protection to much of the shore lands of southeastern Massachusetts. The mass of these islands is, as before noted, of incoherent sand, but the surface is generally occupied by a layer of coarse till or moraine, having a depth of a few feet. As this pebbly and bowldery matter falls to the shore it forms a stony beach. This plating over the soft underlying beds is sufficient to prevent the shore currents from wearing them away. The result is that a platform is made on which the waves break before attaining the shore, and often a barrier beach is formed which to a great extent keeps even the swash from attaining the cliffs. When the adjustment has gone thus far, the shores erode only so fast as is necessary to supply the place of the pebbles which are worn out or the larger waste brought about by the action of the shore ice in rafting away the stones, as it does in a very effective way. An excellent example of the value of these conditions in hindering marine erosion is shown at Gay Head, where, despite the ease with which the strata slip downward into the sea, the vigor of the assault of the waves, and the complete and rapid removal of the sands, the retreat of the escarpment is slower than that of many other less exposed shores on this part of the Atlantic coast line. The bowldery drift, though not large in amount, is enough to have formed a shelf extending irregularly out from the face of the cliffs to the distance of nearly a mile. On this the heavier seas break, so that when running from their prevailing direction only the secondary waves attain the shore, with so little effect that the retreat of the face is at the present time less than a foot per annum and appears to be rapidly diminishing in its rate. On the other hand, the Nashaquitsa cliffs, which in their retreat contribute but little bowldery material to the sea, are, as above noted, retreating at the rate of 3 feet a year, the sea having no difficulty in deepening the bottom as it works in, so that its waves are able to assault the base of the cliffs.

On the peninsula of Cape Cod we find evidence of marine erosion essentially like that on the islands which lie to the southward. The details of this action will be noted in the section of this report which is devoted to the topography of that area, but the general features may well be considered here. The most interesting point is that probably all of the invasion of the sea occurs on the southern and eastern (or outer) part of the peninsula, there being little trace of it on the northern (or inner) shore. This is in part for the reason that the seas strike in times of heavy storm with greater effect in this portion of the coast, but in larger measure it is owing to the fact that strong tidal and shore currents sweep by this part of the coast, which carry away the débris delivered to the sea by many of the cliffs, so that it does not encumber and protect the shores.

On the northern shore of Cape Cod the surface has, as will hereafter be noted, a long riding slope of the glacier, composed usually of clay, which descends gradually to the sea level. This slope extends from the western border of the town of Barnstable to Yarmouth and is partly indicated as far as the town of Brewster. Where this gentle declivity passes beneath the sea, or where it attains the fit depth of water, a beach is formed which incloses the great marine marshes that are so prominent a feature of this part of the coast. This beach is slowly working inland, but the amount of sand which accumulates in the bay it faces is so great that the excavation of the bottom necessary to the inward march of the beach hinders the movement.

On the north shore of Cape Cod the distribution of the products of coastal erosion indicates the weak action of marine currents. On the south side, in the waters between Hedge Fence Shoal and the open sea to the eastward, the distribution of the shoals and spits shows a considerable amount of movable débris in the possession of the sea and its conveyance by strong currents. In the field about Monomoy the struggle between the accumulating sands and the currents is so active that there is evident danger of the passage to the seaward between Nantucket and the cape being closed before many decades have elapsed. If in any time of great storm this channel should become so shallowed that the waves would break across it, the result would be the immediate construction of a barrier beach. If this construction failed to attain to or near the surface, it would doubtless be swept away by the tidal currents. If, however, it made an effective barrier to their flow the island of Nantucket would be again joined to the mainland. An accident of this nature is possible; it is likely, indeed, to be the next great change in the conditions of this part of the Atlantic coast.

As before remarked, the unstable sands of the bays on the eastern side of Cape Cod appear to be mainly limited to the eastern portion of these waters. In Vineyard Sound the evidence from the shores and soundings indicates that the amount of sand at the disposition of the currents and waves is not large. The shores are generally pebbly and the soundings are not to any extent variable. The harbors, such as Tarpaulin Cove, Woods Hole, Holmes Hole, and Edgartown, though so placed that they would naturally be obstructed by moving sands were large quantities of such materials in unstable positions, show little tendency to fill in. The sand beaches, such as those at Menemsha light and between Sengekontacket Pond and the sea, are evidently not gaining in width. These conditions are in very distinct contrast to those which are found in and about Nantucket Sound and Muskeget Channel, where there is a ceaseless oscillation of the shoals and where the harbors which exist are in constant process of closure, against which, as at Nantucket, the precautions of the engineer seem to be of little avail.

The reason for this difference is not perfectly clear; it is probable that it is in part due to the relatively large amount of waste contributed to the sea by the degradation of the shores of Nantucket and Cape Cod, but in a measure also to the fact that the average run of the tides seems to bear the sands to the eastward to a point where the energy of the Atlantic surges, rolling in from the eastward, tends to beat them back into Nantucket Sound.

It seems likely that something like this peculiar condition which we now find in the shoals of the Monomoy group existed a short time ago in the region of Nantucket Shoals, although as yet we do not know enough of these shallows accurately to determine their history. It is probable that it represents the remains of a system of low islands, shoals, and tidal channels which were depressed beneath the sea at the last subsidence. If we should conceive the shore to be 50 feet higher than it is at present, the struggle of the tides and other currents which now exists about Monomoy would be transferred to the region of Nantucket Shoals.

UNDERSTRUCTURE OF CAPE COD.

On first inspection the body of Cape Cod, i. e., that part of it which lies between Monument River on the west and the sand spit which sets in just east of Highland light, appears to be made of glacial débris. It is true that nearly the whole surface is covered either by the extensive moraines which are to be described in the next section of this report or by the deposits of sand and gravel which are spread on the south and east of the morainal accumulations. These superficial accumulations are so extensive that they very effectively mask the true character of the underlying deposits. None of the streams form sections which reveal the underlying beds, and the only cliff shores which do this are near Highland light, where the evidence, as will hereafter be noted, is not very indicative. I therefore deem it necessary to give in some detail the evidence which goes to prove that there are large areas of relatively old strata lying beneath the glacial beds of this district and above the level of the sea.

Beginning with the southwestermost portion of the cape district, that which is in the town of Falmouth, we observe in the fields about Quamquisset Harbor a quality of surface which clearly indicates the existence of deposits other than those of glacial origin. The topography is evidently older than the last ice time, the valleys being somewhat encumbered with deposits of drift. Sections through the ridges show beneath the thin detrital coating a series of somewhat indurated sands, gravels, and clays, usually thin-bedded, though some of the clay layers are 2 feet or more in thickness. The sands and gravels are rather ferruginous, and sometimes the iron oxide is sufficient in amount to produce a distinct cementation. The clay beds range in color from whitish, through brown, to distinct reds. The materials and their association are essentially like those belonging to the Nashaquitsa series, as shown on Marthas Vineyard. The pebbly matter is rarely of crystalline rocks; it consists almost altogether of quartz and quartzite. In the places where shown in rather small openings it seemed likely that the few pebbles of a granitic nature had been brought to the ground by the glacier and crushed into the mass by ice action.

The most notable feature in the "Quisset" Harbor section is the considerable dislocation to which the beds have been subjected. The layers are thrown into short, abrupt folds, the resulting dips being at several points as much as 30 degrees of declivity. The strikes are irregular, but, as on much of Marthas Vineyard, incline to a general northwest-southeast direction. The condition of the folded beds, especially the fact that a topography somewhat obstructed by glacial deposits but otherwise undisturbed was carved on them in pre-Glacial time, clearly indicates that here, as on the island last named, the disturbances can not be accounted for by the movement of the ice. The important exposures which have yielded this evidence were made in 1896 by a land company in grading the roads of its property. They are, unfortunately, of a nature to be soon effaced.

The topography and the distribution of the "spring levels" (or places where the water contained in the drift is turned to the surface by the clays) of the region about Woods Hole indicate that this Nashaquitsa series—for such we shall term it—rises to the prevailing height of about 60 feet above the sea, being capped by the ridge of the moraine which runs parallel with the shore of Buzzards Bay. Northward along the shore of that bay the conditions of surface, as explained by the above-noted facts, indicates that essentially the same materials continue to Buzzards Bay, the ancient series being interrupted only by the indentations which are formed by several "drowned" valleys and by Monument River. In a railway cutting just west of Buzzards Bay station there was exposed in 1896 a section about 4 feet deep which showed stratified ferruginous sands that were slightly folded. These beds appeared to belong to the same series as those at "Quisset" Harbor.

Just east of Falmouth the stream beds near the shore at several points reveal by a little excavating the presence of indurated ferruginous sands and gravels of the same type as those found north of Woods Hole. Moreover, the streams that drain from the eastern face of the Falmouth moraine show that the percolating drainage which is normal to a sand-plain country is interrupted by some resisting layers, which hold the water near the surface. If there were not water-turning beds under these sand plains they would, like those of the similar plains of Marthas Vineyard and Nantucket, drain by percolation to the sea.

The facts above noted warrant the hypothesis that the western section of Cape Cod, say for a strip some 8 miles in width, has a foundation of ancient sands, gravels, and clays which rises to a considerable height above the water level, and is, in parts at least, much dislocated.

It is barely possible that the unseen water-holding layers on the eastern side of this area are of till or other clay beds of Glacial age, but the improbability of this view will be made apparent by the account of similar deposits in other parts of the cape.

On the northern shore of the peninsula, from near Monument River eastward to Yarmouth, and less distinctly still farther eastward to Orleans, there is an often indistinct but clearly traceable slope leading upward from the sea level to a height of 60 feet or more. This slope is often more or less masked by local accumulations of till, or even by small ridges of a morainal nature; but wherever its structure is revealed it is found to be made up of a deposit of dark-blue and gray stratified clays. Its presence is generally attested by the fact that it is not penetrable by water, and the fields which lie upon it are quite different in character from those found elsewhere in the cape district. The agriculture of the northern portion of Barnstable County has indeed been to a considerable extent founded on the quality of this underlying material, which affords a much more enduring soil than is found elsewhere in the area.

Occasional wells on this northern slope of the cape, and particularly the brick pits in Barnstable, show this clay to have the thickness of at least 20 feet. At no point, so far as I have been able to find, has it been passed through.

The clay which so generally forms the northward slope of the cape, between Orleans and Monument River, apparently underlies all the characteristic deposits of the last Glacial epoch. Upon it rests a number of small areas of an evidently morainal nature, as well as a general though rather thin covering of till, which appears at some points, particularly at the brick pits above referred to, to be somewhat churned up with the lower clay. Nevertheless, the distinction between the two deposits is sufficiently clear to show that they are only accidentally associated. Although this clay is to a great extent masked by the usually thin coating of drift, it appears to be continued as a tolerably connected deposit from the western extremity of the cape to Orleans, and perhaps still farther eastward. The fields of this section owe their relative fertility in part to the fact that the clay keeps the water table nearer the surface of the ground and in part to the commingling of this clay with the glacial waste, which in this district is distinctly more clayey than it is in other parts of the cape.

The northern clay of Cape Cod does not appear to have been dislocated by compression strains, at least none such have been seen in the scanty sections which are exposed to view. As to the origin of the deposit, the evidence is not yet clear. So far as ascertained, the material contains no fossils. In its general aspect it is like the well-known brick clays of southeastern Massachusetts, which were, in some cases at least, clearly formed at the time of, and in front of, the glacial sheets during the last ice advances. Yet, as no pebbles have been found in the deposit, and as its resemblance to some of the beds of the Nashaquitsa series of Marthas Vineyard, which clearly antedates the last ice epoch, is evident, it will not be safe to class it as of Glacial age. It is, perhaps, the equivalent of the Tisbury clays of Marthas Vineyard.

South of the glacial clays, and generally beneath the moraine which extends from Monument River to Orleans, the evidence, though imperfect, goes to show the existence of another series of clays, which exhibit a general likeness to those noted as occurring in Falmouth near Quamquisset Harbor. In my opinion this ridge of older clays forms the greater part of the considerable elevation, which at first sight appears to be entirely of a morainal nature. The evidence in support of this proposition is as follows:

Along the line of the moraine, which attains at several points an altitude of nearly 200 feet, we find that the depressions of the surface, up to 150 feet, often contain water for a large part of the year. Even where they are not temporary pools, these kettles commonly exhibit up to or above the last-named height a degree of wetness which indicates that they rest upon more impervious materials than the very porous moraine affords. An index of the same nature is to be found in the height of the considerable lakes, of which a score or more are shown on the topographical map of this part of the cape. Thus, Peters Pond, in Sandwich, is about 95 feet above the sea, and a number of the other lakes exceed 50 feet in altitude. In general, it may be said that the lakes in the central portion of the cape, particularly those within the limits of the distinctly moraine topography, stand at heights above the sea which clearly indicate that the barriers which retain the water are much less pervious than the sandy, pebbly, and bowldery matter of the moraine itself, which in this regard is but slightly more effective than the washed drift. The same considerations lead us to extend the clay area much to the southward of the southern face of the moraine. The lakes on the sand plains for some distance out from the face of the moraine lie at heights which exclude the supposition that their waters are retained by the interstitial friction or resistance to percolation which is normal to washed drift. On the sand plains of Marthas Vineyard the value of this friction, as is shown by the depth at which water has been struck in the central portion of the island, is not more than 2 to 3 feet to the mile. On Cape Cod many of these lakes of the plain are at heights above the sea which would afford grades of from 12 to 15 feet to the mile from their low-water mark to mean tide. On this account, as well as from the general statement which is had from all those who are familiar with the history of the wells of the district, that they usually strike clay before attaining the level of the sea, I judge that the central clays of the island probably extend some distance south of the moraine.

As to the character and altitudes of the central or submorainal clays of the northern part of Cape Cod, the evidence yet gathered, though not extensive, is, taken with what has been found near Woods Hole, sufficient to show something of these conditions. In the section between Great Pond and West Barnstable the roads show some small sections of grayish-white bedded sands unlike any glacial beds known to me. The beds dip to the southeast at angles of from 8 to 10 degrees. Traces of reddish-brown clays are revealed in the same district.

In the town of Dennis, at the side of the State road, the cuttings at the time they were made revealed dark clays and gray sands, thinly bedded, resembling the Nashaquitsa series. These beds are folded on a north-south axis, the amplitude of the arches, so far as could be ascertained, not exceeding 50 feet. Although these foldings were not very plain, they were recognized by my companion, who had no special knowledge of geology, as arches having the form shown in the diagram, fig. 88.

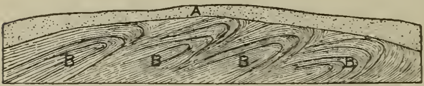


FIG. 88.—Diagrammatic section showing position of folded clays, State road, Dennis. A, glacial drift; B, folds in (Truro?) clays. 1 inch = 100 feet.

In the town of Brewster, about one-half mile east of the station of that name, there is a considerable area (100 acres or more) in which the drift covering is so thin that the under clays are revealed. These appear to be somewhat confused next the surface by the rubbing and scouring action of the glacier. It is thus impossible, in the slight exposures, to determine the exact attitude of the beds, which are of grayish and blue sandy clays and red clays, the last of the general aspect of those at Gay Head. Near Griffiths Pond—now a cranberry bog—a considerable exposure of the red clay on the north side of the road to the station shows not very clearly a rather steep dip to the northwest. Although the scanty showing of these clays in the small pits by the roadside does not afford distinct evidence of steep dips, the distribution of the outcrops indicates such attitudes, with a prevailing strike N. 45° E. These clays rise to about 100 feet above the level of the sea.

From Schoolhouse Pond to East Brewster station the clays, apparently of the same general nature as those last described, lie everywhere near the surface on the south side of the main road. The deposit rises to the height of from 100 to 110 feet above the level of tide. Its upper surface forms a tolerably gentle slope to the northward, on which rests the morainal heaps and into which the kettles seem to be cut, with the result that they are usually very wet at their bottoms. The red or reddish sandy clays appear also, though obscurely, in some of the roads of East Harwich which lie to the south of the section last described.

In Orleans the older series seems to be present thoughout the greater portions of the area of the town. It is scantily revealed in the road cuttings, and is shown in an effective way only on the southwest side of Town Cove, just east of Tonset. Along this shore the deposits are not enough exposed to give a clear idea of their attitude. They are all dark colored and are related to the glacial beds in the manner indicated in the accompanying diagram, fig. 89.

The above-described clays appear to continue for some distance northward into Eastham. The precise line where they cease to rise above the level of the sea has not been determined; it can not be ascertained without pits or borings. It seems likely that this limit is not far from North Eastham station.

On the south side of the moraine there exists a series of clays which are revealed in the ordinary domestic wells that are driven in this section. I have been unable to find any of these wells in process of excavation, and am therefore limited as to information concerning the section to what I have been able to gather from various persons whose statements seem worthy of trust. These persons agree that for a considerable distance south of the moraine in Harwich, to within a mile or so of the sea, these wells strike a dark-colored clay ordinarily at a depth of 10 to 20 feet below the surface. This deposit usually has to be passed through in order to obtain water, which is found in thin layers of gravel above a lower-lying clay. The thickness of the upper clay is said to be 10 feet or more; the lower clay deposits do not appear to have been passed through.

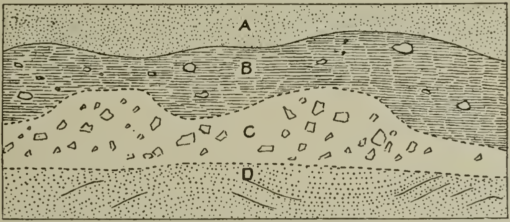


Fig. 89.—Diagrammatic section of post-Glacial clays, west side of Town Cove, one-half mile south of its head. A, glacial sands; B, stratified clays; C, till; D, folded clays and sands. 1 inch = 10 feet.

The statements concerning the existence of a series of clay layers beneath the sand plain on the southern side of the Cape Cod moraine are in accordance with the evidence afforded by the levels of the lakes in this area. As before remarked, these lakes, especially those which are situated within 2 or 3 miles of the morainal area, have a height above the level of the sea which is inconsistent with the supposition that they are fenced in by no more effective barriers than would be formed of the open-textured sand and gravel of the plain in which they lie. These lakes are, in part at least, to be regarded as occupying old valleys, which slope down to the northward and have been barred across by morainal accumulations of a clayey nature, which have in good part effaced them.

As to the attitude of these clay beds, which lie beneath the whole or a large part of the southern morainal plain of the cape as far out as Orleans, there is no basis for accurate determination. The reports from those who have sunk wells in the area leads, however, to the supposition that the deposits are not dislocated after the manner of the central series, but lie in approximately horizontal attitudes, dipping gently to the southward. It is thus tolerably clear that the fundamental structure of the body of the cape—at least that part of it lying between Monument River and Eastham—consists of a central axis of more ancient clays and sands, having in part at least the general aspect of the Nashaquitsa series of Marthas Vineyard, and being likewise much disturbed by orogenic action. On the flanks of this older axis of elevation lie the clays, which, as before noted, appear to form the north and south slopes of the area, and on which rest the relatively thin layer of glacial waste—the moraines and sand plains which give the surface aspect to the region.

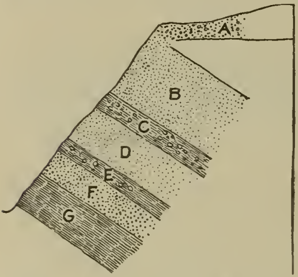
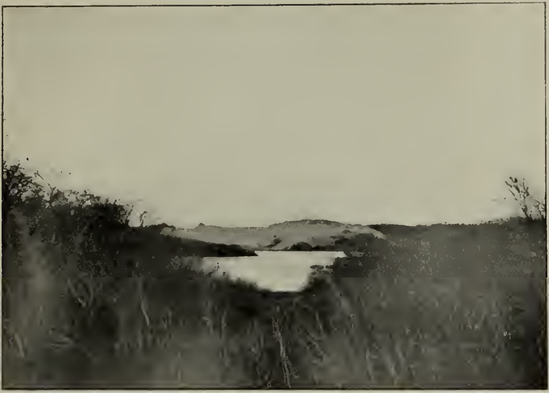
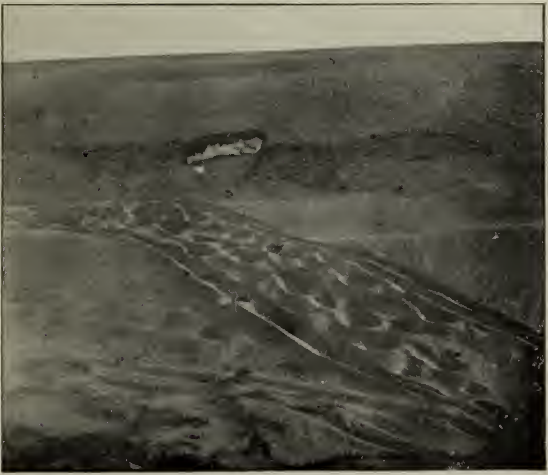


FIG. 90.—Diagrammatic section near Wellfleet bridge, in Truro. A, glacial drift; B, D, F, stratified sands; C, E, pebbly sandy clays; G, fine clay. 1 inch = 5 feet.

The outer portion of the cape—i. e., that between Orleans, or perhaps the northern portion of Eastham, and the extremity of the peninsula—has a structure which indicates a history somewhat different from that just noted. In this outer part the older dislocated beds with the red clay layers do not appear above the water level, or if they rise above that plane they are completely covered by the later-formed deposits of clays and sands. In this area we have a succession of beds, indicated in the accompanying fig. 90, which shows a series of events somewhat different from that exhibited in the district to the westward. In this section, from central Eastham to the end of the highland at Moon Pond and Salt Meadow Pond, the beds consist of certain clays which appear, so far as can be determined by their general nature and relations, to be essentially similar to those beds which were noted as occurring on either side of the Nashaquitsa series of the western district of the peninsula. Upon these clays occur beds of much-decayed sands and gravels, which in character are somewhat like those found in the subglacial portion of the section on the west side of Town Cove in Orleans. Owing to the large showing made by the glacial deposits of



A. DUNE POND, PROVINCETOWN.



B. NEAR VIEW OF DUNE SURFACE, SHOWING MASS OF BURIED SNOW.

this part of the cape, this series of sands and clays has been assumed to be the product of the ice age. Although the question as to the age of the several divisions of rocks of this field is in the main to be dealt with in a later part of this report, it may here be said that there is good reason to doubt whether the beds shown in Wellfleet and Truro should be reckoned as of glacial origin, at least in the sense that the sand plains in the more eastern section are to be so reckoned. They have exhibited no glaciated pebbles; they lack the surface slope so characteristic of morainal aprons, and they fail to exhibit the occasional large ice-rafted bowlders so common in such deposits.

From the northern end of the highland of the cape to the extremity of the peninsula the land is, so far as its surface is concerned, made up altogether of sands, which have been brought into their position by the recent action of marine currents or of the wind. As has been shown by Professor Davis, the form of the slope which terminates the elevated ground toward Salt Meadow Pond indicates marine erosion before the outermost part of the cape had been built. As will be hereafter noted in more detail, this agglomeration of sand hooks and spits most likely rests upon a portion of the land which had been cut away by a set of currents different from those now prevailing on this shore.

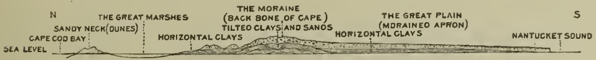


FIG. 91.—Diagrammatic section across Cape Cod from West Barnstable station to Osterville, showing the general structure of the area west of Orleans.

The construction work involved in the formation of dunes is admirably shown in this portion of the cape. By the exercise of a certain amount of care in planting, the local and State authorities have succeeded in arresting the movement over a large part of the area, but the seaword portion of it is still in constant motion. The speed of this movement may be judged by the fact that in April, 1897, a mass of snow 20 feet in length and 2 feet in thickness was revealed where it had been covered with sand during the preceding winter to the depth of 12 feet, the mass having been subsequently cut through by a change in the scouring movement of the wind. (See Pl. XCVII, *B.*)

The irregular deposition of the dunes has led to the formation of a number of small lakes, which, though of no geological significance, are very picturesque. They are generally bordered by a fine growth of scrubby trees, nourished by the moisture they afford, while beyond this fertile margin rise the desolate slopes of sand. (See Pl. XCVII, *A.*)

HISTORY OF THE CAPE COD SERIES.

As already indicated, the beds exhibited in this area may, so far as they have been interpreted, be provisionally divided into five groups, of very unequal value as regards their extent or the time occupied in their formation. • These groups are, in order of age, as follows:

First and lowest, the series of gravels, sands, and sandy clays which, on the basis of general aspect, are here reckoned as the equivalent of the Nashaquitsa series of Marthas Vineyard, and which, as on that island, have been subjected to a considerable amount of stressing.

Second, the dark-colored clays which are revealed at the brick pits in West Barnstable, at the base of the section on the west shore of Town Cove, at the base of the section at Highland light, and at various other points: these are known as the Barnstable series. These pits are occasionally much filled. Their position in relation to the other groups remains somewhat doubtful.

Third, the sands and clays characteristic of the Wellfleet and Truro district, found along the shore northward to Plymouth Harbor, and probably northward to Egypt or Coleman Heights, in Scituate. It is not unlikely that remnants of these beds occur in other portions of southeastern New England.

Fourth, the glacial deposits, including the morainal accumulations, the eskers, and the sand plains which lie south of the moraines.

Fifth, the beds formed since the Glacial period, consisting of dunes, spits and hooks, submarine coast shelves and shallows, and the organic deposits of swamps and marshes.

These five groups of deposits will now be considered from the point of view of their geological history.

NASHAQUITSA SERIES.

The identification of this series, as exhibited in Cape Cod, with that found at the typical locality on Marthas Vineyard, rests altogether upon the general, though close, resemblance of the physical characteristics of the deposits. In both we have the same gray measures—sands intermingled with sandy clays, which have a red or reddish hue; in both the pebbly element is scanty. In the Cape Cod exposures the red beds are more prominent than on Marthas Vineyard, but in both cases the hue is less pronounced and the clayey element less considerable than in the more ancient deposits of the Gay Head Miocene series. It seems likely that these reddish clays have in each case been derived from the washing over of the older Tertiary deposits. That such is the case on Marthas Vineyard admits of scarcely any doubt, for the reason that there the later beds contain fossils which evidently came from the erosion of the earlier series.

It is hardly to be supposed that these red clays of Cape Cod could have been derived from a field so remote as that of Gay Head. As may be seen at the last-named point, the eroded clay is not carried any distance by the tidal currents. We are, therefore, compelled to suppose that the beds in Cape Cod were derived from some areas of the Gay Head series which have been completely eroded away, or at least lowered beneath the sea level by the wearing to which they have been subjected. The remnant of the Miocene rocks which exists in Marshfield, on the mainland to the north of Cape Cod, lies in a depression of the crystalline rocks, where it has been in a measure protected from erosion. It is eminently probable that these beds once occupied the district between Marshfield and the base of the cape. They may, indeed, have had a much greater areal extent.

The probability that the deposits of the series found at Gay Head and elsewhere on Marthas Vineyard once extended over a wide field in the cape district is made the clearer by the fact that remnants of the greensands, as is well known, occur at Marshfield, Massachusetts, north of Plymouth, and apparently also below the level of the sea in one or more points in the Monomoy group of shoals. The evidence as to the existence of the beds at the last-named point is incomplete, but it deserves a brief statement.

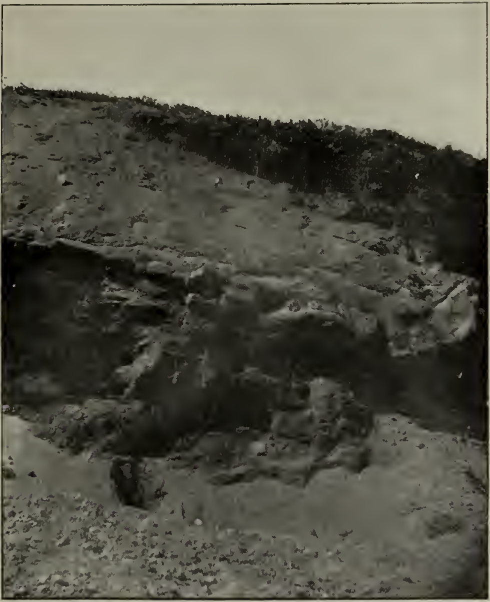
Among the shallows in the Monomoy area is one sometimes known as Stone Horse Shoal. This eminently curious name points to some peculiar feature in the history or structure of the place. I am told by Capt. John L. Veeder, of Woods Hole, that some years ago he was engaged in breaking up the wreck of a ship which had been for some time lying on that shoal and had become partly embedded in the sands. When the hulk rolled over it brought up a quantity of "dark sand" which contained many fragments of bones. In answer to my inquiry Captain Veeder stated that the material was like the greensands of Gay Head. It is well known that sailors are apt to class any bones as those of horses.

As to the nature of the erosion which provided the material for the Nashaquitsa series, there is little distinct evidence, and that is of a negative character. The beds on Marthas Vineyard have afforded fragments of magnetic iron ore, apparently from Cumberland, Rhode Island, and other materials which may be from the same field; but it is to be observed that the pebbles may not have been derived directly from that locality, but may have come, as is the case with much of other materials, intermediately from deposits of Tertiary or Cretaceous age. As these beds were apparently deposited not long before the advent of the last Glacial period, the question arises whether they indicate any form of ice action. To this inquiry a negative answer must in general be given. None of the pebbles are scratched or faceted; there appear to be no ice-rafted blocks; the fragments are all small, the greater part of them of quartzitic or felsitic nature, the ordinary crystalline rocks, such as are so plentifully exhibited by the glacial deposits of the last ice period, being of scant occurrence. In general the pebbles are much waterworn and affected by superficial decay, which shows that they have been long separated from their original bedding places.

The transportation of the materials of the Nashaquitsa series appears to have been effected, in part at least, by strong and variable currents, as is shown by the stony cross bedding of the sands. At other times, and with sudden alternations, the conditions were such as allowed the deposition of fine-grained clays in these layers. It is a noteworthy feature of the formation that it contains, so far as ascertained, no indigenous fossils of a recognizable nature. This, taken in connection with the fact that on the west end of Marthas Vineyard (where alone the series is well exhibited) there are a great many organic remains of animals derived from the Tertiary rocks, goes to indicate that, though the conditions of deposition and of subsequent time favored the preservation of fossils, none were contributed to the formation by creatures living in the waters. This inorganic aspect of the beds may be due to any one of several conditions existing in this district at the time of their formation. It may have been due to the presence of a glacial sheet; but this hypothesis is less warranted than is the supposition that the deposition took place rapidly in a fresh-water basin much in the manner in which deposits are now accumulating in the basins of certain great lakes, as, for instance, in Lake Ontario near the mouth of the Genesee River. The evidence afforded by the beds is, indeed, most consistent with the view that they were thus formed in a fresh-water or estuarine body into which large and sediment-laden streams were discharged.

At first sight the supposition that this portion of the continent was the seat of considerable lakes during or about the Pliocene epoch may seem to require an excessive difference from the existing geographical conditions. It is, however, evident that the Atlantic shoreland from the Carolinas to Nova Scotia has from the beginning of the Mesozoic to the present geological time tended to develop extensive lacustrine areas. In Triassic time these areas of fresh water were numerous and large, the basins having a character and an extent comparable with those of the eastern flank of the Rocky Mountains during the Cretaceous period. A part at least of the Gay Head series, including the plant beds of the Cretaceous and a portion of the Miocene, appears to have been deposited in areas of fresh water. It is not necessary to suppose that these areas of fresh water were completely separated from the sea; they may have been estuarine in their nature, much as are the sounds of North Carolina and other portions of the southern coast of the United States.

The question arises as to the original extension of the deposits of the Nashaquitsa series. As yet they have been definitely observed only on Marthas Vineyard, in the islands of the Elizabeth Archipelago, and in the area we are now considering. It is likely, however, that beds of equivalent age exist in Block, Fishers, and Long islands. Deposits of perhaps the same age may exist farther to the south, though until fossils are found in the Massachusetts area there will be no sufficient means of fixing the age. The fact that these beds are found scattered over a considerable area in the manner before noted indicates



A. SECTION OF PART OF TRURO SERIES ON NORTH SIDE OF PAMET RIVER, NEAR BRIDGE.

B. VALLEY EXCAVATED IN TRURO SERIES, CHILTONVILLE, PLYMOUTH.

that they were at one time extensive. The height they now occupy, notwithstanding the considerable erosion to which they have been subjected, shows that they must have been formed when the level of the sea was much higher than at present. Thus on Marthas Vineyard they lie at not less than 200 feet above the tide, and their upper surface has shared in the erosion which has served to develop an old and deeply incised topography on .the area. It is, indeed, necessary to assume that the upper surface of the deposit originally lay at a far higher level, perhaps 100 feet or more above its present plane.

As to the dislocation of the beds, this seems to have occurred before the erosion which formed the valleys in which lie the bays and sounds that separate the known location of the deposits. The time of the dislocation can not be more definitely stated than that it was after a part, at least, of the Pliocene had been deposited and before the deposition of the Barnstable clays or the Tisbury beds, which apparently lie above them. The interval between these stages was evidently of considerable duration, even in the geological sense of the word, for it included not only the time occupied in the folding but also the period required for a considerable erosion of the beds.

Concerning the extent of the dislocations which have affected the Nashaquitsa series, it may be said that it was much less intense and general than that which is recorded in the Gay Head section. In the area occupied by the last-named group of strata, about 30 square miles in extent, the average dip of the beds is about 45°, and no part of the layers, so far as seen, remains in a horizontal attitude. In the case of the Nashaquitsa series the greater portion of the Marthas Vineyard area is but little dislocated, and on Cape Cod the average departure from the original horizontal attitude is apparently only a little greater than it is on the Vineyard, probably not averaging more than 10° of declivity.

The foregoing considerations justify the supposition that the Nashaquitsa series originally occupied an area along this portion of the shore of the continent; they warrant also the belief that this area was, after a slight though distinct dislocation, carved into an extended topographical relief and that the surface of its more salient points was considerably lowered in the process. We have to suppose that this carving was, in the main at least, due to river action, though the valleys may have been affected by marine agencies after they were lowered beneath the plane of the sea.

THE BARNSTABLE SERIES.

After the formation of the topography cut in the Nashaquitsa series had been effected the district was again depressed beneath the sea. The downward movement certainly brought the coast line at least 100 feet above its present level, for the Barnstable clays attain the elevation of 60 feet above tide, and the Tisbury clays, their probable equivalent, rise to about 90 feet. As these clays, particularly those of the Barnstable area, have the character which belongs to deposits formed at some distance from the shore line, it is likely that the down-sinking was to a much greater depth than is here indicated.

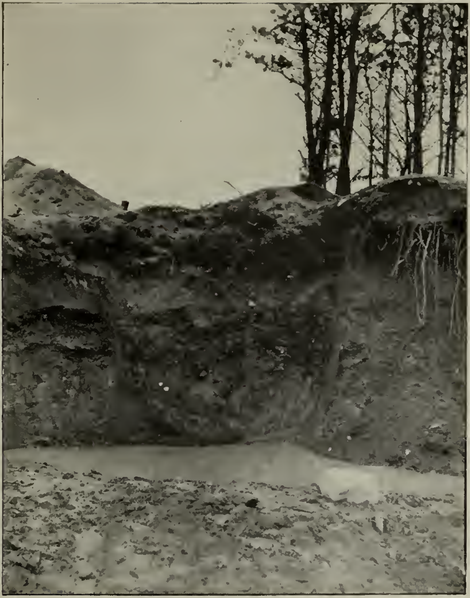
Clays of the same general nature as those of the Barnstable series occur along the shore to the eastward as far as Chatham, though the best exposures known to me are those on the present marine escarpment and in the clay pits at Barnstable; there they seem everywhere to underlie the glacial deposits, being usually separated from them by a variable thickness of apparently pure glacial sands and clays.

It is not unlikely that some of the brick clays lying farther northward and westward on the mainland, as well as other deposits in Harwich, are of the same age as those of the Barnstable series, but their discrimination is difficult and has not yet been effected for the reason that they do not apparently differ in any distinct way from those of later date and of undoubted glacial origin.

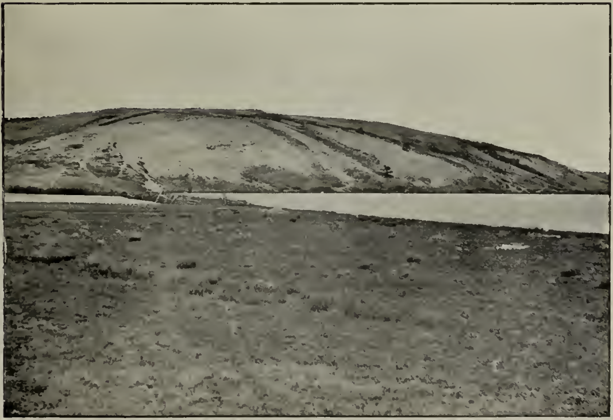
The gravels in the clays of the Barnstable series are known to me only by the reports of those who have penetrated the beds in sinking wells. They are described as composed of small pebbles, mingled or coated with iron oxide.

The Barnstable beds, as has already been suggested, may be the equivalent of the Tisbury beds of Marthas Vineyard. The evidence of the identity of age is, it must be confessed, not very strong. It rests altogether on the fact that in both cases clay beds not greatly disturbed by the mountain-building forces rest upon the disturbed Gay Head series, and that they have both been elevated to a considerable height and carved by erosive agents. To suppose that the two series are of diverse age would require the assumption that there had been one more cycle of erosion, subsidence, and elevation in the Pleistocene period, which is already overcrowded with actions of this nature that I have been compelled to postulate in order to explain the geological structure of the district.

As against the supposition of the identity of age of the two sets of beds, it may be said that the Tisbury series forms a distinct, though much eroded, bench on the north side of the island of Marthas Vineyard. There is no evidence that they ever had a very wide lateral extent. The beds are mottled yellow and bluish clays and sands, with occasional bowlders of small size, which may possibly have been ice-rafted to their present positions. The materials of the strata have apparently been derived from the erosion of the Cretaceous and Tertiary beds of the dislocated area against which they lie. It seems quite possible that with the advance of our knowledge of this district it will be found that the Barnstable beds, which appear to have been formed in deep water in an offshore position, are not to be regarded as in age the equivalents of the Tisbury beds, which were evidently formed nearer the shore and in a shallower depth.



A. STREAM CHANNEL CUT IN CONTORTED CLAYS, NORTH WARWICK STATION.



B. HILL NEAR CHATHAMPORT; TRURO SERIES, DRUMLOID OUTLINE

It is to be understood that evidence of a diversity in age of the glacial clays and of the beds here referred to as related to the Barnstable series is not perfectly clear. I see no reason to doubt that the formation of the deposits which lie beneath the cape and the region to the northward as far as Plymouth Harbor clearly antedate the last ice epoch, but some of the clay beds of the cape district may have been deposited during the time when the ice work was in progress. It should also be noted that even if the glacial origin of the Barnstable series should be proved, the evidence is still to the effect that the ice action was not that of the last advance, but an epoch separated from it by events which indicate the lapse of a great interval of time. This will be more evident in the sequel.

TRURO SERIES.

The characteristic Truro series is even more generally concealed than are the beds which lie beneath along the eastern shore from Wellfleet to Highland light. They are, it is true, revealed in the wasting cliffs, but the amount both of slipping and of loose débris is so great that it is not possible to determine further the character of the section than that it is composed of a hundred feet or more of fine, gray, micaceous sands and sandy clays in frequently alternating beds. These beds apparently contain no fragments of compound rocks; the only pebbles they carry—and these are small and of infrequent occurrence—are composed of white quartz. The beds appear to be somewhat disturbed, but the irregular sliding of the cliff as it is undercut by the sea makes this apparent evidence of orogenic stress untrustworthy.

At only two places has it as yet proved possible clearly to ascertain the true attitude of the beds in the Truro series. One of these is a pit whence clay for hardening roads has been taken. It is on the north side of Pamet River, immediately south of the road, and a few hundred feet from the bridge over that tidal stream. The section is as shown in Pl. XCVIII, *A*, and in fig. 90, p. 534. The materials consist of alternating clays and sands, such as are shown on the cliff at Highland light, even bedded and quite without pebbly matter except bits of rounded quartz. They lie at an angle of about 18°, dipping northwestward. There is a thin layer of pebbly drift on the top of the section. (See Pl. C.)

Another exhibition of these beds is in a clay pit 200 or 300 feet north of South Wellfleet station. Here the beds are at higher angles than in the section near Pamet River bridge; in part the slopes are of 30° or more. The bedding, indeed, seems to be crushed as it is at certain points on Marthas Vineyard. Here, as in the last-named section, there is a thin overlay of pebbly washed drift, with small rounded bowlderets.

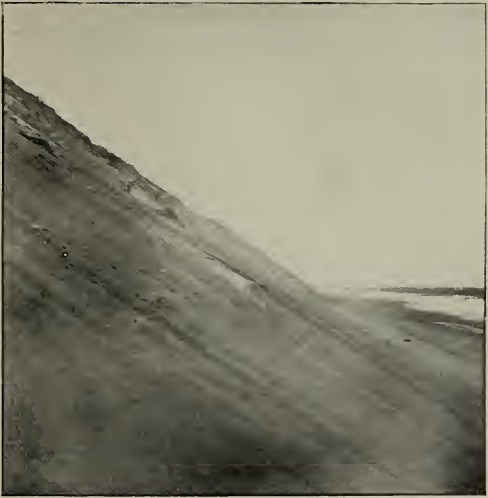
It should be noted that the sections above described were obtained at the only points where the attitudes of the Truro series could be clearly discerned. Taken in connection with what has been observed on the cliff shore and in a considerable number of obscure artificial exposures, there is evident reason for believing that the strata of this series are generally dislocated much as are the beds of Tertiary age on Marthas Vineyard.

It appears to me unreasonable to suppose that the steep dips of the beds of the Truro series are due either to cross bedding or to glacial thrusting. The sections examined are sufficiently extensive to reveal the true structure. They show nothing to arouse the suspicion that these slopes are due to deposition on the construction point of the stratum. As for the thrusting, there is, as is elsewhere noted, no good reason to believe that the glacier ever eroded this surface. If it did so, its action was not vigorous enough to have eroded the delicately molded pre-Glacial topography.

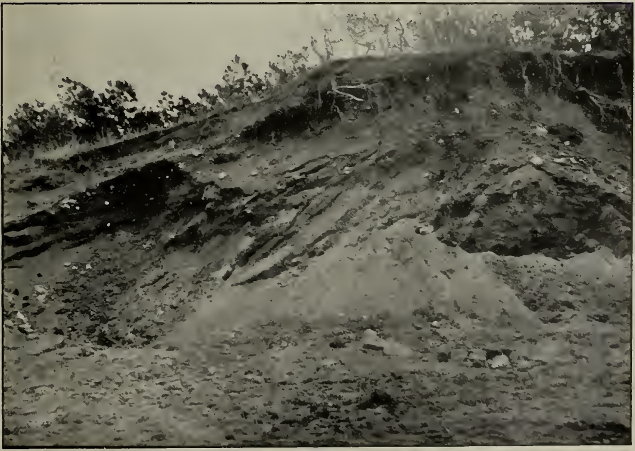
The feature which most distinctly separates the surface aspect of the Truro sands from that of the morainal aprons is their slope. This is not, as in the sand plains of Barnstable and elsewhere, toward the open sea on the east, but distinctly toward the bay on the west. The surface is, it is true, to a certain extent encumbered by the waste left upon it in the last advance of the ice; but making allowance for this coating, it is quite evident that the slope, instead of being outward from the ice front, was inward toward the face of the glacier. If, indeed, the deposit is to be regarded as a sand plain, it will have to be assumed that the ice lay outside of the cape, discharging its waste westward toward the bay, a view which is manifestly inconsistent with all we know of the distribution of the glacial envelope on this part of the shore.

Taking no account of the deformations of the surface in Truro and Wellfleet, which have been brought about by the small amount of glacial waste which the area bears, the westerly slope is clearly indicated either to the eye of the observer in the field or by the inspection of the topographic map, where the contours are seen to lower as we pass from the outer or eastern to the inner or western side of the area.

As we pass from the eminently characteristic surface of the sand deposits of Truro and Wellfleet toward the southern and western parts of the cape, the glacial deposits thicken and become more irregular, until in Orleans the Truro sands are to a great extent concealed by this drift. Nevertheless, beds of the same general nature are noticeable at most points where a natural or artificial section is carried to any considerable depth in all the area as far west as Yarmouth. They are particularly well shown in Dennis and Harwich, and are also revealed in the southern parts of Brewster and the northern portion of Harwich. It is here, as in the typical localities of the series, quite evident that the surface was deeply incised by the action of streams before the last invasion of the ice, which served to encumber and at times efface the preexisting valleys, though the erosive action which conveyed this waste was not sufficiently intense to cut away this rather delicately molded topography. Throughout the area in which these



A. TALUS SLOPE, HIGHLAND LIGHT.



B. CONTORTED TRURO CLAYS AND GRAVELS NEAR CHATHAMPORT.

ancient sands are traceable they generally rise on the crests of the ridges which they occupy to the height of about 100 feet above the level of the sea. It seems likely that while glacial erosion, mainly if not altogether due to streams from beneath the ice, may have cut down these crests to a certain amount, the extent of this wearing has probably been not more than a few feet.

The original extent of these Truro sands is, on account of the erosion to which they have been subjected, not clearly determinable. It seems, however, to have been great, as will be seen from the following notes concerning the distribution of beds apparently of that age which occur in a fragmentary manner in and about Cape Cod. In the western part of the cape there is reason to suspect that deposits of this age underlie the ridge of the Falmouth moraine. Exposures of yellow sands are shown at a number of points on the western face of the moraine in positions which indicate that they are portions of a large area which extends beneath this mass and rises to a considerable height beneath it. On the island of Naushon, the northernmost of the islands of the Elizabeth Archipelago, orange-colored sands with characteristic absence of coarse waste underlie nearly, if not quite, all of the area and rise to the usual height of about 100 feet. Southward throughout this group of islands to Penikese beds of this character and presumably of the same age are seen here and there, evidently lying in the Nashaquitsa series. On Marthas Vineyard the series is less well shown, yet it is tolerably well indicated on the northern side of the island at Copoggan Head (misnamed on the maps Cape Higgon), as well as at other points between Menemsha Creek and West Chop. They are also seen in the retreating escarpments of East Chop and West Chop and the sea face at Cottage City.

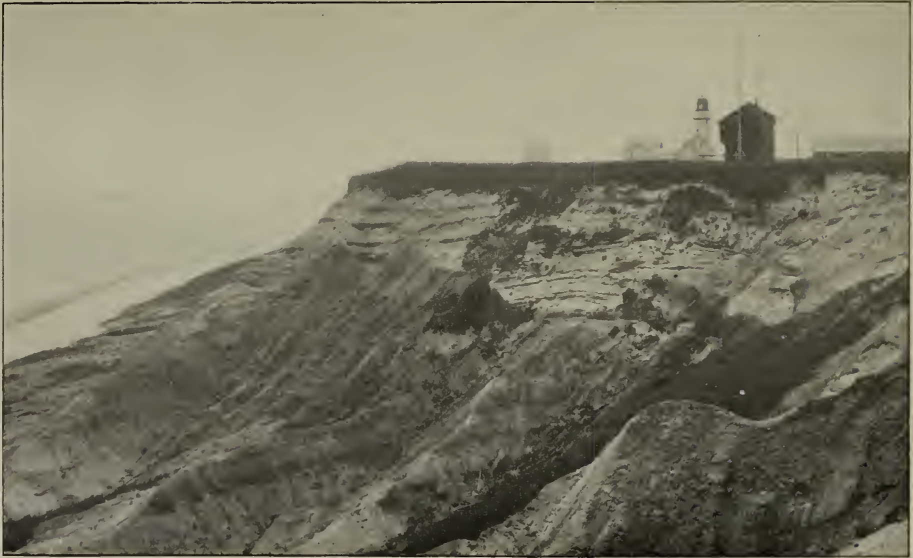
Beneath the great plain of Marthas Vineyard, the upper portion of which is clearly of the character proper to morainal aprons, there is revealed by occasional wells extending to the depth of 70 to 90 feet a deposit of yellow sands with no large pebbles, which appears to belong to this group. Here we have to suppose that the beds had been worn down by marine or other action to a level somewhat below that which they occupy elsewhere and then sheeted over with the deposits formed during the last advance of the ice. In the valleys of Tisbury and Tiasquan rivers, in the central part of Marthas Vineyard, and at Gay Head there are traces of the same sands, which are scantily revealed and only discriminable from the deposits of the Nashaquitsa series by the characteristic yellow hue.

West of the base of the cape, along the southern shore of Massachusetts, deposits which may be compared with those of the Truro series are not clearly disclosed and may not exist, though the search for them has not been carried so far as to make their absence certain. In Rhode Island, as has been suggested to me by my colleague, Mr. J. B. Woodworth, beds of this age may underlie the Charleston moraine, where, as remarked by the late J. D. Dana, stratified sands appear to underlie the morainal deposits. The scanty outcrops of these beds in their appearance warrants the supposition that the formation has the same general character that it exhibits in the localities before described.

North of Cape Cod, along the shores of Massachusetts Bay, the Truro sands, overlain by distinct glacial deposits, are abundantly exhibited. On the shore of southern Plymouth, from point to point, they form the marine escarpment. (See Pl. CIV.) In the high ridge of Manomet Hill they probably attain the height of 250 feet or more above the level of the sea. The erratics, which are so abundant on the ridge and which give it the character of a moraine, form only a relatively thin coating on the summit of a pre-Glacially-formed ridge, resulting from extended subaerial erosion of the inferior sands. (See fig. 92, p. 555.)

North of Plymouth the curious table-land known as Egypt Heights, in the southern part of Scituate, appears to be composed of beds in character quite like those at Truro. The general form of this curious deposit of sand can best be explained by the supposition that it is the remnant of a large area, and not a local deposit accumulated during the last Glacial epoch. This view is supported by the general character of the material, which is much the same as that of the Truro section, though it is more deeply covered with recent glacial waste. Scattered patches of the same decayed sands continue to the northward as far as Boston Harbor. In that basin, mostly below the level of the sea, a thick deposit of sands clearly antedating the last ice epoch has been revealed by artificial sections, as in the tunnel for the Moon Island sewer, and particularly in a well boring made on Deer Island. At the last-named locality a thickness of 300 feet was passed through, the beds being in general character like those before described, except that the oxidation was less complete than at the other parts. The evidence goes to show that here, as elsewhere, this section of decayed sands with few pebbles is immediately, though discordantly, overlain by the bowldery drift. North of this point on the shore I am not aware of any sands which may be referred even conjecturally to the Truro series.

In the district of southeastern Massachusetts, remote from the shore, I am aware of but one locality where deposits of much-oxidized sands having the general character of those before described are clearly revealed. This is at Prospect Hill, in the southern part of the town of Raynham and the western part of Taunton. At this place we find an irregular ridge, composed mainly of sands with a few pebbly beds, capped in part by a layer of bowldery nature, which gives the mass something of the aspect of a moraine. Some years ago I came to the conclusion that the greater part of this ridge represented a much-eroded deposit, which was formed before the last ice advance and which had been scantily affected by a morainal accumulation made



TRURO SERIES AND GLACIAL BEDS, HIGHLAND LIGHT.

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in that stage of the Glacial period. It now seems most reasonable to regard this as a remnant of the deposits of the Truro series.[1]

It is probable that many other deposits of well-oxidized sands which exist in southern New England will eventually be found to represent the same epochs of Pleistocene time as those above catalogued. At present they are naturally, and it may be inextricably, confused with the accumulations of washed drift which were so plentifully formed in front of the ice during the later advances of the glacier. As will be further noted in the study of the glacial deposits of Cape Cod, the Truro series may possibly be but the outer remnant of a broad sheet of shore sands formed during the earlier epochs of the Glacial period, when the margin of the ice lay at some distance north of the present shore, and that this moraine accumulation passed into other types of glacial waste as it approached the ice front.

The facts before noted make it probable that at some time before the advent of the ice of the last Glacial period in the region about Cape Cod the surface of the land was at a much lower level than it is now—at least 100 feet lower—and that at that time an extensive sheet of water-borne sands was deposited on the sea bottom. It seems necessary to suppose that this sheet was laid down as a tolerably continuous outward-sloping formation, such as is now found in the continental shelf along the Atlantic coast. It certainly could not have accumulated in the patches and ridges in which it now appears. We can not, for instance, suppose that the crest which forms the foundation of the Elizabeth Islands, and which rises about 150 feet above the present level of the sea floor, or that of the Truro Plateau, which attains a like or greater height above the bottom of Cape Cod Bay, was formed as we now find it. We are forced to assume that these evident remnants of erosive work were originally parts of a widespread deposit, by far the greater part of which has been swept away.

The time of the erosion of the Truro sands, which reduced the area of the formation to the few remnants we now find, clearly antedated the last advances of the continental glacier. This is indicated by the facts that the position of the remnants is that which they would occupy if they were left by water erosion, but not such as would exist if the wearing had been effected by ice, and that the preexisting rather delicate topography, such as would have been carved by stream action, was not destroyed by the glacial erosion. In illustration of the first of these points it may be said that the ridge of the Elizabeth Islands is precisely such as would be brought about if it had been a divide between the supposed rivers of Buzzards Bay and Vineyard Sound, but in no way could it well be explained by glacial or marine erosion. As for the second, the many pre-Glacial channels on the Truro-Wellfleet plains show how even delicately sculptured valleys were not completely defaced by the wearing influence of the glacier which came upon them in its marginal and attenuated form, if indeed they were ever actually beneath the ice.

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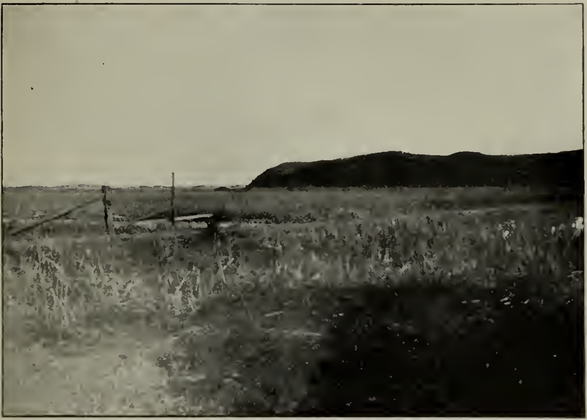
[1] Since this report was written beds apparently the equivalents of the Truro series have been found by the writer at a number of points in southeastern New England.

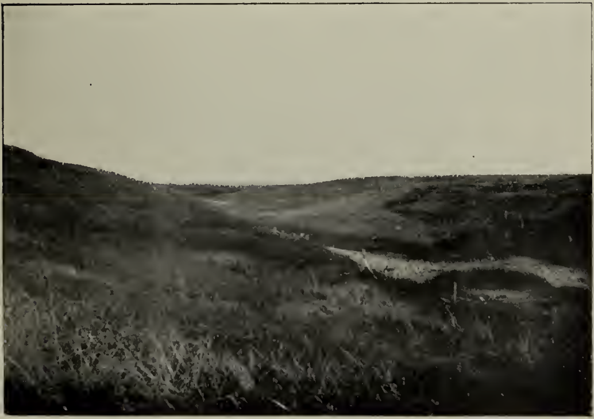
As for the time when the erosion of the Truro sands was effected, we may confidently place it in the later part of the long interval which is partly, at least, recorded in the well-developed subaerial topography which was made on Marthas Vineyard after the cessation of the dislocation of the underlying beds and before the advent of the ice of the last Glacial epoch. As before remarked, this interval was long, for the work done during it was vast. It is clear that the Truro beds were formed after this topography was pretty well completed, for beds referable to the age lie partly in the valleys due to the erosion in question. It is thus evident that the greater part of the erosion of these later sands came after the shape of the Vineyard topography had been in large part determined, but probably before the valleys thereof had attained anything like the present development. (See Pls. CII, CIII.)

The reduction to a plain of the Truro sands was probably in part effected by the action of the sea. As may be noted along the shores where these beds are subjected to the action of the waves and marine currents, the beds wear away with exceeding rapidity. It may, however, have been in considerable part accomplished by ordinary stream action, as is shown by the persistence of many ancient valleys in those parts of the cape district underlain by these deposits. It is, however, difficult to believe that this stream erosion took place under the present conditions of climate and geography, for the reason that the beds of these ancient water ways are no longer occupied by streams, except, perhaps, on the rare occasions when, on a frozen earth, melted snow or rain is deprived of its usual exit by percolating into the porous underlying sands. The absence of water in these channels is probably to be attributed in part to the fact that they have been greatly shortened by the cutting away of their headwaters, so that the water now flowing seaward in their drainage is less in amount than of old, being no longer more than can pass through the interstices of the sands, through which it more readily finds a passage because the way to the sea is not so long as of old. It is probable, however, that the amount of the rainfall has in geologically modern times diminished in this region, as elsewhere on this and other continents, so that the capillary channels are able to afford storage and passage to all the precipitation. It may be observed that in times of any great rainfall sandy plains occasionally for a short time develop superficial streams, the water quickly ceasing to flow when the precipitation stops.

The rate of the erosion of the Truro beds wherever they are assailed by either marine or fluviatile agents is made the greater by the fact that the beds are destitute of coarse débris, which, in the case of the till, brings about the formation of a more or less effective revetment on the erosion face that hinders the action of waves or currents.



A. MOON POND ESCARPMENT, FACING PROVINCETOWN SPIT.



B. BEHEADED WATERLESS VALLEY JUST SOUTH OF HIGHLAND LIGHT.

Moreover, the very lean nature of the soil causes the growth of vegetation to be slight in amount, so that the protection of this sort which is usually so important is scanty. Thus the wearing rate on this group of deposits is likely to be very much greater than it is on such beds as form the Tertiary strata of Marthas Vineyard, frail as the latter appear to be. (See Pl. XCVIII.)

The most important indication pointing to the origin of these Truro sands is the apparently entire absence of fossils in the section. In the extensive outcrops which I have inspected no trace of organic matter has appeared. It seems clear that the beds were laid down under conditions which were peculiarly unfavorable for the inclusion of organic remains, or that such remains were subjected to some process which utterly removed them. Although, as before noted, these beds are considerably oxidized, it can not well be believed that fossils once present have been utterly destroyed. The Tertiary sands of Virginia and elsewhere are equally affected by decay, yet the mulluscan remains are fairly well preserved. Assuming, then, that these beds were originally formed without organic remains, the probability is fairly established that their materials were brought into the sea by glacial action. In no other way does it seem possible to account for the formation and deposition of such a mass in a marine or lacustrine area. It is to be said that this view has its difficulties, among which we may reckon the apparent absence, as before noted, of all ice-rafted blocks in the beds and the lack of clay in the greater part of the section.

Taken in connection with the seemingly nonfossiliferous clays of the Barnstable series, the Truro beds may perhaps be regarded as a stage in one of the several cycles of a glacial period. It is a well-recognized fact that the glacial flour or fine débris, which in the ordinary course of glaciation constitutes the larger part of the detritus that is formed, is normally carried much farther away from the front of the sheet than the sand, and that this in time goes farther than the pebbly matter. We may thus reckon that the Barnstable clays are the outer or relatively remote accumulations of an ordinary glacier, and that the Truro sands were laid down when the ice front was nearer the present shore line. If this view be accepted, we must then suppose that in the ice epoch which brought about the formation of this series—probably not the last Glacial epoch—the glacial sheet did not quite attain to this field, and that the land lay at a lower level than it does at present. As is clearly indicated by the extensive erosion which followed this period of deposition—erosion in which the glacier appears to have had no part—the time intervening between the formation of the Truro beds and the advance of the ice sheet which deposited the till, moraines, kames, etc., of the district must have been great. It was assuredly many times as great as that which has elapsed since the last of the ice sheets left the field.

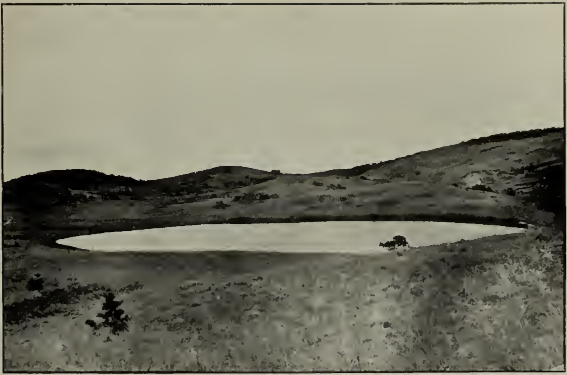
Although the matter has been before stated in a fragmentary manner, it may be well again to call attention to the accumulation of evidence which exists in this field going to show the very great length of the time which has elapsed since the close of the Pliocene. In this interval there were evidently three distinct periods of erosion, each of long duration, and an equal or greater number of widely varying changes in the position of the land in relation to the sea. As measured against the geological work which was done in these periods, that brought about since the close of the last ice advance is relatively of little account, being limited to slight changes of level and to a small amount of marine cutting, the subaerial wearing being quite insignificant, perhaps not the one-hundredth part of what was done in the earlier stages of the so-called post-Tertiary. It thus seems that, basing the measure on a vaguely assumed rate in the alteration of organic forms, we have most likely much underestimated the duration of this division of the earth's history.

CONDITION OF THE DISTRICT AT THE BEGINNING OF THE LAST GLACIAL EPOCH.

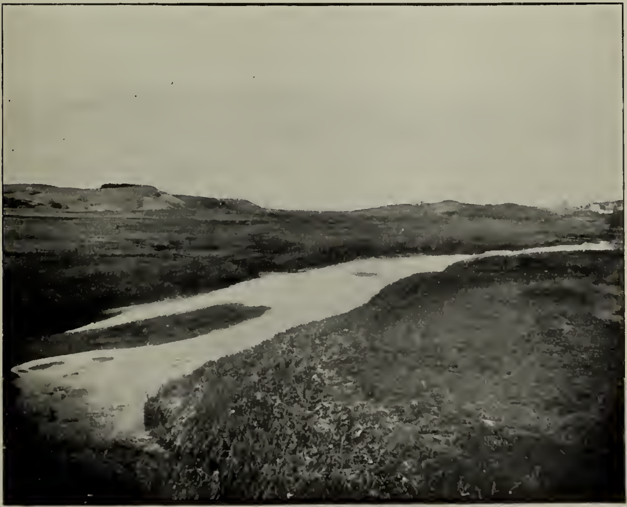
The conditions of height and shape of the land in this area immediately before the advent of the ice of the last Glacial epoch appear to be approximately determinable. It is tolerably evident that the land lay at a higher level in relation to the plane of the ocean than it does at present. This is indicated by the existence of the flooded drainage basins, which have been already in part described. These drowned valleys include not only the greater basins of Cape Cod Bay, Nantucket and Vineyard sounds, and Buzzards Bay, but many of the divisions or branches of these wide valleys where the streams tributary to the effaced rivers now enter the sea. Thus, on the islands of the south as well as on the mainland all the valleys which are now or have been in former times the seats of streams are flooded at their mouths.

On the north shore of Cape Cod we find a number of pre-Glacial channels which slope toward the bay of that name, and which evidently were at the time of their excavation the beds of streams discharging into a river that flowed northwardly to the shore line, which was farther out seaward than at present. These old valleys may be traced from Duxbury to the northern part of Truro. They point toward the central portion of the submerged trough in a normal and most suggestive manner. On the body of the cape these channels are generally much occluded by the deposits of glacial drift. They are to a considerable extent deformed by the scouring action of the streams which flowed beneath the ice sheet while it lay over the country.

The first of these channels of Cape Cod to be noted is that of Monument River, which now is a tidal stream discharging into Buzzards Bay. As it is clogged at its northern end by drift, it appears as a tributary of the ancient stream which occupied the valley of Buzzards



A. TOPOGRAPHY CHARACTERISTIC OF THE TRURO SERIES; VALLEY OBSTRUCTED BY GLACIAL DRIFT.



B. BLUFFS OF TRURO SERIES, PAMET RIVER VALLEY.

Bay. The form of the trough, which distinctly widens to the northward, suggests that it originally flowed into Cape Cod Bay, and that the ridge which originally parted it from the waters of the south was cut through by a torrent which flowed through this depression in the time when the basin to the north was occupied by the glacier. Eastward along the north shore of Yarmouth the streams appear to have been short and to have drained north and south from the highland now covered by the moraine, and which is locally known as the "Backbone of the Cape." The valleys of these streams draining northward are now but faintly traceable in the confusion of the morainal drift. On the south side of the ridge the valleys are to a great extent lowered beneath the frontal aprons of stratified materials, yet they may be indistinctly and in a general way traced by the depression in which lie the lakes and the streams which drain them.

At Bass River we have another instance in which a pre-Glacial valley (or valleys) has been enlarged and deepened by a current from the glacier. At this point there seems originally to have been two streams, one flowing northward, the other southward. The subglacial stream cut through the ridge between them, converting the trough into a broad way, which practically divides the cape, so that a trifling expenditure would suffice to make a water way from the north to the south side of the peninsula.

East of Bass River as far as Orleans the central ridge of the cape continues; the valleys become less and less blocked with till and morainal waste. This is especially the case on the north side, where the valleys in Dennis and Brewster channels, with rather obscure digitations pointing toward Cape Cod Bay, may be well traced. Beyond Orleans the ancient central watershed disappears, the sea having eaten into it from the east, and the larger valleys usually run across the width of the peninsula. This feature is best shown at Pamet River (see Pl. CIII), where one of these depressions appears—after the manner of the valleys of Bass River and Monument River—to have been depressed and widened by a glacial stream until it completely divides the peninsula, so that there is only a sand beach at the outer side to unite the farther part of the cape with the body of the area. There are, however, many lesser valleys which slope to the northward and which seem essentially river ways, though they are no longer occupied by streams. These troughs appear to be beheaded at their upper or outer ends, their conditions suggesting that their headwaters lay in the lost territory which has disappeared by recent marine erosion (see Pl. CII). In the account of the Truro beds it has been suggested that the former presence of streams on these now dry valleys may be accounted for by the above-suggested diminution of their drainage area, or perhaps in part by the diminished rainfall which appears generally to have attended the disappearance of the glacial sheet and which may have been the cause of its shrinking.

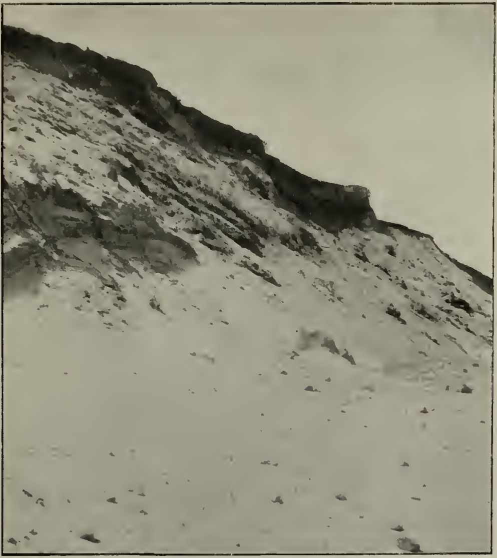
It is evident that the shape and size of Cape Cod shortly before the time when the glacier came upon it differed greatly from what we now find. In place of the narrow peninsula, in form like the flexed arm of a man, was a broad salient which extended as a connected land to some distance beyond the outer margins of Nantucket and Marthas Vineyard. At this stage the sea level probably stood about 200 feet lower than it does at present. During the time when the ice lay over the district it was depressed to a level at least 100 feet below where it now stands. This permitted the formation of the great sand plains of Marthas Vineyard, Nantucket, and the cape. When the ice departed the land in part resumed its old height, rising a little above its present elevation, and then sank, as is shown by the submerged forests which occur from point to point along the shores.

GLACIAL HISTORY OF THE DISTRICT.

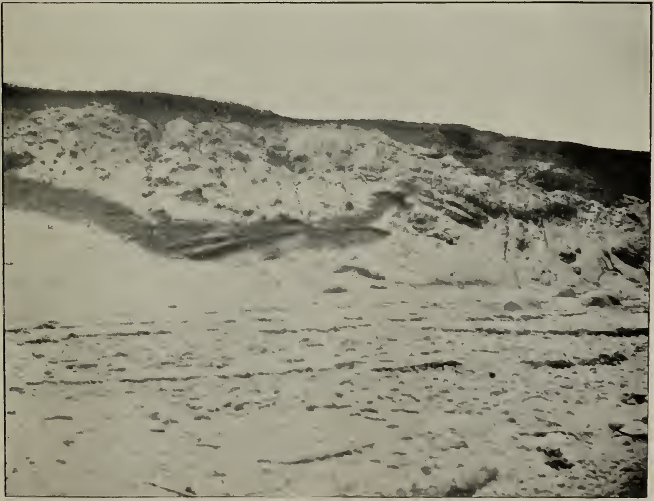
It has already been noted that the deposits contained in the strata from the Miocene to the Truro series, inclusive, suggest the existence of glacial action in this part of the world at various times since the middle Tertiary; but unless the lower Pliocene beds of Gay Head attest the actual presence of ice, there is no reason to believe that it ever rested upon this field until the last epoch. Even in that time the sojourn of the glacier was evidently brief and the work which it did of relatively slight structural or geographical importance. It has already been noted that the general character of the surface had been determined by pre-Glacial conditions The valleys and ridges existed in general about where we now find them, only now they are to a great extent filled with glacial waste.

It seems pretty clear that immediately before the advent of the glacier the surface of the cape was carved into a topography such as is likely to be formed on clays and sands by the headwaters of streams. The valleys were rather deep and steep-sided. Where the clays come to the surface these valleys appear to have had something of the sharpness of the "bad-lands" topography of the western country. This is shown by the indented character of the old surface of the Nashaquitsa beds on Marthas Vineyard, where it is revealed in the coast sections. It is indicated on Cape Cod by the sharp ridges of clay, the so-called "pounds," which occasionally appear at the surface, projecting through the thin envelope of drift. The generally slight value of glacial erosion in this district is best shown on the island of Marthas Vineyard, where, as noted in previous reports, the wearing has been so slight as to leave the pre-Glacial topography essentially undisturbed except by the filling of the valleys with detritus.

On Cape Cod the actual erosion work is little if at all greater than on the islands of the south except in the case of the valleys which were cut through by the streams flowing from beneath the glacier or



A. SHORE BLUFF SOUTH OF SHIP POND, PLYMOUTH, SHOWING TRURO SERIES DIPPING STEEPLY NORTHWARD.



B. SHORE BLUFF SOUTH OF SHIP POND, PLYMOUTH, SHOWING TRURO SERIES FOLDED AND FAULTED.

under the roof of ice. Of these the most characteristic examples are Monument and Bass rivers. The channel of Pamet River is perhaps another example of the same nature.

There seems no evident reason why the subglacial streams which were on their way to the open water of the ocean should have climbed the ridge of the cape on the south in place of turning directly to the east around its extremity, which was then some distance south of the site of Provincetown. In view of this departure from the most direct way of escape, it may be suggested that as the ice fell back to the northward it may for a time have inclosed a lake between its retreating face and the concave north shore of the cape. In this case breaches would naturally have been formed to permit the discharge of this water from the melting ice through to the sound on the south. It is, however, not certain that any part of the cape was above the level of the sea at the time when the retreat of the ice took place. The only strong point in favor of the view that these channels were glacial stream beds is the fact that they are cut down to the sea level practically throughout their whole length, and that their forms indicate the passage of a current from the northward, and in the case of Monument River there is a considerable area of stratified sands near its mouth, on Buzzards Bay, which may well be taken as the delta formed where the current poured into that basin.

DIRECTION OF THE ICE MOVEMENT.

As the rocks of Cape Cod and the neighboring parts of southeastern Massachusetts are not of a nature to receive glacial scratches or groovings, the only indications of the direction of the ice flow are those afforded by the positions of frontal moraines and the direction in which erratics have been transported. It should be said that the moraines in this section present such discrepant evidence that conclusions drawn from their positions are not trustworthy. The transported blocks, therefore, furnish our only information, and this is in the main unsatisfactory.

In the western section of the cape, from Monument River to Orleans, the common petrographic elements of the moraine and till are granitites and the dike stones associated therewith, such as are found on the mainland. As these rocks occur along the shore from the parallel of Plymouth to Cape Ann, and may extend an indefinite distance eastward along the sea bottom, no precise evidence as to the course of the ice is to be obtained from these fragments. Eastward from the base of the cape there appears to be a constant increase in the amount of rocks of more evidently volcanic origin, such as are found sparsely about Cohasset and along the north shore of Massachusetts Bay. The deposits of this nature on the mainland are rather too limited to have afforded the large quantity of waste that appears in the cape. It seems likely that they have been derived from beds which lie beneath the sea.

So far as this evidence goes, it seems to show that the direction of the glacial movement on Cape Cod probably did not depart from the general trend indicated by the scratches observed at the nearest points on the mainland, or between north and north 30° west.

ENERGY OF THE ICE MOVEMENT.

As has been already noted, the energy of the glacial erosion in this district appears to have been but slight. It did not suffice to wear away a rather delicate antecedent topography. On the western part of the cape the transporting power of the ice was sufficient to carry a great number of erratics, many of which are of large size, thousands of blocks each containing from 100 to 300 cubic feet being exposed on the surface of the principal moraine. In the period of its greatest extension the ice apparently passed over the ridge of the cape as far east as Orleans, crossed the valley of Nantucket Sound, and deposited on the island of Nantucket the slight morainal masses which there exist, and which perhaps mark the extreme advance of the ice on this part of the coast.

North of Orleans and thence to the end of the cape there is no distinct morainal accumulation, but occasional wide heaps of drift and the clogging of the pre-Glacial valleys show that the surface was traversed by the streams pouring forth from the glacier. The general lack of erratics other than those which may have been ice rafted, or of any accumulation which can be classed as a moraine, or even as distinct till, shows that at this point the glacier, if it actually lay on the surface, was probably so weak and thin that it had no longer any considerable abrading or transporting capacity. The conditions here resemble those found on the southern part of the highland of Marthas Vineyard, where large portions of the surface are nearly driftless.

Although the carrying power of the ice as marked by the accumulations of erratics was not great, that of the streams which flowed from beneath the glacial sheet was excelled, so far as I have found in New England, only by those which deposited the great sand plain of Marthas Vineyard. As to the extent of the deposit, that of the cape is unexampled elsewhere in southern New England. The area is probably not less than 120 square miles, but the thickness appears to be much less than that of the like mass in the island to the south.

GLACIAL DEPOSITS.

The deposits due to the direct action of the glacial sheet are the till, the moraines, and the washed drift accumulated in the eskers and the sand plains.

The till deposits of this district are neither extensive nor characteristic. Along the north shore especially the areas are immediately underlain by the Barnstable clays. The coating is evident, but very irregular; in places it is so thick as to resemble a morainal accumulation; at others considerable tracts appear to be quite without the deposit. Toward the eastern extremity of the cape the coating becomes thinner and less recognizable. Angular erratics are rare in the section beyond Yarmouth, and beyond Orleans few erratics greater in size than those termed by Chamberlin "bowlderets" are found, and these appear to have been conveyed by floating ice.

Between Orleans and the northern portion of Truro the till becomes a mere confused mass of the materials of the local beds over which the ice has passed in its movement, with occasional erratics of moderate size which were brought from a distance. It is difficult to recognize it as a distinct element in the sections, for it is essentially wanting over large areas of the surface.

The morainal deposits of the Cape Cod district, though less extensive than those found in the central parts of the continent, are by far the most characteristic in New England, presenting phenomena which are in many ways peculiar. They deserve, therefore, the detailed consideration that will here be given them.

The moraines of southeastern Massachusetts are singularly distributed. In southern New England they lie usually in lines which are evidently almost at right angles to the direction of the ice motion, and variations from this position can usually be explained by the topography of the bed rocks over which the ice moved; but in the cape district, including the neighboring islands and the mainland, the ridges are set at curious angles to one another. There the following directions may be noted:

On the mainland the Plymouth moraine, which extends in a general southerly direction from near the harbor of that name, appears at first sight to be the largest, and is perhaps the most continuous, deposit of the kind in New England. In its northern portion, at least in Manomet Hill, it is underlain by the Truro beds, which arrangement has given a false impression as to the depth of the glacial waste. With some interruptions it is continued southward to Monument River, at the base of the cape, in an approximately meridional axis as far as Woods Hole, and thence, deflecting westward about 30°, it is continued down the Elizabeth Islands nearly to their southern extremity.

On Marthas Vineyard there are two evident morainal belts parallel to that of Falmouth—one on the north side of the island, which is characteristically developed; the other in the central section, which is faintly shown, but can be traced by scattered patches of bowlders. On Nantucket there is a small area of moraine on what is known as Sauls Hills, but the axis of the accumulation is not well indicated; it appears to be in a general east-west direction.

On Cape Cod, occupying, as before noted, the high land formed by the ancient divide of the tilted series of beds, there is a morainal mass extending in an east-west direction from Monument River to the

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eastern part of the town of Brewster; it may be regarded as continued in a slight form into the western part of Orleans. It is to be observed that this ridge lies at nearly a right angle to the course of the Falmouth moraine, with which it, in effect, coalesces at its western end. Although the general direction of this moraine is east and west, its shape is somewhat concentric, the curve being toward the south, the most southerly part thereof being near Bass River. It is thus evident that there are two distinct alignments of ice-morainal ridges in this district; the one, that which is clearest in its direction, being meridional in the Plymouth ridge, but deflected to a northeast-southwest course in its more southern elements; the other having essentially an east-west course.

So far the diverse positions of the moraines in the Cape Cod district have been explained by the theory of lobations in the front of the glacier, portions of the ice sheet pushing out in broad tongues, each of which made its frontal wall. These walls formed successively, intersecting one another in much the same manner as that of Falmouth intersects that of the cape. While in nowise doubting the adequacy of this explanation as applied to the interior districts of this country by Chamberlain and others, I am compelled to question its applicability to the field now under consideration, for the following reasons:

The Cape Cod district comprises no strong topographical features which could have caused the ice sheet to flow in the directions which would have to be postulated if these several moraines were formed at right angles to the axis of movement. It is unreasonable to suppose that, while the general course of the ice in the neighboring interior district was from northwest to southeast, it should have been directly southward in Massachusetts and Cape Cod bays and directly to the east in the region about Plymouth. On the contrary, the natural conditions, so far as they can be ascertained, would have led the ice in these bays to flow eastward toward the open sea and not southward toward the high ridge of the cape. I have therefore been compelled to seek another explanation of the axial order of these moraines, and have framed what seems a plausible hypothesis to account for this order without having recourse to the theory of lobation of the ice front, which has its difficulties, as just noted. This hypothesis is, in effect, that the moraines of the Cape Cod district are not of the ordinary type, but belong to a hitherto unrecognized group of hilltop drift accumulations, which, though essentially morainal in their nature, were formed under peculiar conditions, rendering them of slight value as indices of the direction of the ice movement.

It has already been incidentally noted that certain parts of the several moraines described in this report rest upon antecedently formed ridges, which, in effect, were the ancient drainage divides of the country. Let us now examine the several deposits to determine how far this peculiar character is possessed by the moraines in general. Beginning with the northernmost of these ridges, Manomet Hill, in Plymouth, it will be found that the elevation is composed mainly of stratified sands, apparently of the Truro series, as has been recently shown by the excavations made in lowering the grade of the State road, which traverses the northern end of the ridge. In other words, the mass of the ridge is of pre-Glacial age, and was probably a divide between the headwaters of the Buzzards Bay river and that which drained the basin of Cape Cod Bay. So far as can be ascertained, the same underlay of sands extends beneath the rather indistinct morainal ridge that continues the Manomet Hill deposit southward to the base of the cape. These sands are not clearly seen, in sections, to pass beneath the morainal belt, but are exposed near by in positions which make it tolerably certain that they must underlie it in the manner of a pedestal, as in the case farther north. (See fig. 92.)

The Falmouth continuation of the Plymouth ridge is by far the longest and most united mass of morainal material yet noted in New England. It extends from Monument River to Woods Hole without any breach in its distinct wall, which rises to a height of from 100 to 200 feet above the sea level throughout its length of about 18 miles. As this belt is but little traversed by roads which have been at all graded, and as its surface is covered by a dense tangle of scrubby vegetation, it is not easy to obtain sections which reveal the nature of the underlay. At Woods Hole and thence northward for about 4 miles there is abundant evidence that the moraine rests upon a ridge of older deposits. On the western face, nearly as far north as Gunning Point, the underlying clays of the older series can be traced, rising from the shore to the height of from 60 to 80 feet. Here and there along the main highway which skirts the shore to Monument River the conditions of the soil and the level of the streams also indicate that the same ridge of older rocks persists beneath the morainal cap, attaining perhaps at some points between the valleys of the brooks a height of more than 100 feet above the level of the tide. On the east side of the ridge the streams and lakes show by their levels that the ridge continues on that side of the moraine. The facts justify the conclusion that the greater part of this morainal ridge rests on the summit of a pre-Glacial divide which separated the waters of the old Buzzards Bay river from that which formed the valley that is now Vineyard Sound.

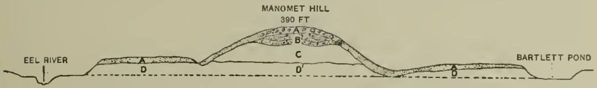

FIG. 92.—Diagrammatic section of Manomet Hill, Plymouth. A, glacial deposits; B, observed Truro deposits, 100 feet; C, supposed Truro deposits, 150 feet; D, sands and clays of unknown age, 100 feet; D′, supposed continuation of D beneath the hill.

With a change of direction from north-south to northeast-southwest the Falmouth moraine is continued southward in the Elizabeth

Islands. In these isles the erratic material is in all cases but a thin overlay resting upon the crest of an ancient ridge cut in the Naushon sands, which are considered the equivalent of the Truro series. At no point, so far as I have observed, does the moraine appear to be more than 25 feet thick. In all the observed localities it evidently rests on the top of a divide formed before the advent of the ice, and it is lacking over large areas, where the stratified sands appear with only occasional bowlders resting upon the surface. Of the mass of material composing the Elizabeth Islands above the plane of the sea, certainly not a tenth, and perhaps not a twentieth, part is of morainal nature. The rest may be of glacial origin, but if so, it was deposited far in advance of the ice and long before the advent of the glacier in this part of the field.

On Marthas Vineyard the main or northern moraine appears at first sight—and even after some inspection—to be made up of bowldery material, but on careful investigation I have found that it is a pre-Glacial ridge, the pedestal being formed of a stream divide cut in the Cretaceous and Tertiary strata. On account of the misleading appearance of the ground, I was led, in my report on this island,[1] much to overestimate the depth of this glacial wall. It has not half the mass stated in that report. It is doubtful if the average depth of the deposit exceeds 40 feet. The ridge occupied by the moraine is not completely covered with the deposit. For considerable distances the top of the elevation is essentially without materials which, from their character or distribution, may be classed as truly morainal. At other points, especially in the middle portion of the belt, on the estate known as "Seven Gates," the deposit constitutes a very characteristic morainal belt, with numerous large kettle holes and with bowlders in such abundance that the masses appear like ruined cyclopean masonry. The southernmost moraine of the island also occupies the summit of a divide, but the erratic element is small in amount and only here and there assumes a morainal character.

In the territory between the two moraines of Marthas Vineyard there are, as before noted, many fields which are so far free from glacial waste that they may fairly be termed driftless. It is not easy to find any material on them that may be classed even as till. Rarely is there a foot, in depth, of this deposit. This driftless character of surface is so complete that the plowshare will turn up Tertiary or Cretaceous beds containing no trace of erratics. Fields of this driftless soil some acres in extent lie within 2,000 feet of the wall-front moraines. On the north side of the principal moraine the same phenomenon of nearly driftless fields is observable, but in a less distinct manner. The areas without erratics are small, and those which are quite without till are at no point, so far as I have observed, more than an acre or two in extent. They occur at the foot of the slope on which the moraine lies, usually quite near the sea level. This feature of small driftless areas over which the morainal matter must have passed on its way to the glacial front indicates that the conditions which determined the deposition of the detritus were peculiar.

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[1] Seventh Ann. Rept. U. S. Geol. Survey, 1886, p. 312.

There is another peculiarity of the Marthas Vineyard moraines which appears to throw some light on the conditions of their formation. While commonly the ridge of detrital material is placed on the very crest of a divide, adding distinctly to its height, it not infrequently is deposited as a sheet on the southerly or outer face (outer in relation to the glacial movement) of the ridge on which it was formed. The effect is as if the materials had been pushed up the northern slope and had fallen into the attitude in which they are found.

In the case of the Cape Cod moraine the evidence is sufficient to show that the mass occupies the considerably elevated surface of a ridge which was formed before the advent of the ice. This ridge continues with no complete interruption from the base of the cape to Orleans, except for the rather deep and wide break at Bass River. So far as I have been able to determine, the moraine is gathered mainly on the southern side of this ancient divide, though it generally rises somewhat above the crest line. The feature noted on Marthas Vineyard, of considerable areas of the more ancient deposits without glacial waste, is noticeable to the north of this moraine, but is less extensively developed than on that island.

On Nantucket the moraine appears to crown the summit of an elevation composed of the Sankaty beds, which probably belong to a time immediately preceding the deposition of the Nashaquitsa series. The conditions are not clearly indicated, but there is little reason to doubt that this relatively unimportant accumulation is placed as are the others above noted.

The facts above described warrant the statement that all the characteristic morainal accumulations of this district are placed in singularly close relations to the crests of ridges which existed before the ice sheet invaded this district. The few apparent exceptions prove on examination really to be not such. Of these the most striking is the case of the northern moraine of Marthas Vineyard, where the bowldery deposit descends into a valley about the headwaters of Witch Brook. In this relatively low place, which still is about 70 feet above the sea, the moraine becomes somewhat scattered. It is, in effect, a rather flat, very stony field, in place of the well-defined accumulation exhibited on the higher ground on either side. So, too, the same morainal, detached hills which lie here and there on the north slope of Cape Cod and Marthas Vineyard appear on inspection to be small elevations of the Barnstable series, which bear some coarse drift or else masses dropped from a stranded iceberg.

The relations of the moraines in this district can not be explained on the supposition that these deposits are revealed only on the highlands, being elsewhere covered by later accumulations of washed sands. This suggestion would not be entertained for a moment by any student of the district who approached the problem without a decided preconception; although, as I know from experience in making the examination, it requires rather careful observation to avoid the mistake of supposing that the whole mass of these several ridges is of a morainal nature.

So far as I am aware, none of the moraines of the central and western portions of the country are placed on the crests of divides in the manner shown to be the rule in this shore-land district; nor am I aware that any of the accumulations in the interior parts of New England occupy the crests of ridges, except when their bases may accidentally coincide with those elevations. It therefore may be fairly assumed that there has been some peculiarity in the condition of the glacier in this part of the country which has served to bring about the curious result. I have not been able to determine the precise cause of this occupation of the preexisting divides by glaciers, but the possible explanations appear to be but two, and these will be briefly stated.

The first hypothesis is that the ridges may have served in forming a moraine by arresting the flow of the ice, already languid in its movement, for the reason that it had become attenuated at its margin. Hanging on these crests its front may have been retained in one position for a considerable time, which permitted the accumulation of the morainal deposit. The difficulty with this view is that it does not explain the absence of drift in the fields near the well-developed morainal lines. The second hypothesis is that, the region being depressed beneath the sea to a considerable but unknown depth, the ice, while remaining as a united sheet, may have floated over the valleys, grounding only upon the ridges and there depositing its contents of rock material. The portion of the ice which was shoved over the crest was probably broken into fragments which floated away. This hypothesis will explain the absence of till on much of the lowlands where, had the ice rested on the surface while it melted, it should remain to mark the decay of the sheet.

The hypothesis of the partial floating of the attenuated ice sheet finds a certain amount of support in the evidence which goes to show a considerable subsidence during the period of formation of the sand plain in front of the moraines. As I have elsewhere shown, these plains were certainly formed under water while the land lay at least 100 feet lower than its present level, and the actual depth of the submergence may have been much greater than the minimum required for the construction of the plains. The hypothesis will perhaps serve to explain also the departure of the Cape Cod moraine from the normal direction. As before remarked, it is very difficult to see how a glacier moving under ordinary conditions would have a path parallel to the shore; but if the sheet be conceived as floating in the sea, though its course might be generally eastward, its margin might be pressed continuously or from time to time against the submerged ridge on the south, on which would be dropped, as the ice sheet shattered or broke up into bergs, a portion of the contained débris. The main objection to this hypothesis is that evidence as to the actual floating of the ice over the valleys is lacking; yet it demands only conditions which must exist wherever a glacial sheet enters the sea, pushing out into water so deep that the mass leaves the lower-lying parts of the bottom. Somewhat in its favor is the fact that over the nearly driftless fields near the Marthas Vineyard moraine occasional large solitary erratics are found, and sometimes heaps of coarse débris in positions which suggest that the materials have fallen from the base of a floating glacier or from an iceberg.

It must be confessed that both hypotheses present serious difficulties; but in view of all the facts, the one last stated is more satisfactory than that of marginal lobes producing interlocking moraines—a hypothesis which does not seem applicable to this field.

RELATIVE AGE OF THE MORAINES.

The relative age of the moraines in this district affords an interesting field for inquiry. The only criterion which appears to be accessible is that which may be derived from the comparative amount of decay of rocks of apparently the same measure of resistance to such change. Judged by this test, the moraine of Cape Cod is to be regarded as rather newer than that on Marthas Vineyard; the bowlders of like petrographical species are less broken up, and interstitial decay has penetrated to a much less depth. These determinations are based on mere inspection, but the impression thus obtained by many successive visits to each field at short intervals is clear.

Much evidence as to the petrographical nature of the hidden rocks of southeastern Massachusetts and the neighboring sea bottom can doubtless be obtained from a careful study of the materials in these moraines. This task has not been formally undertaken in the preparation of this report, but incidentally certain points have been noted, of which only one need be mentioned here, viz: On Marthas Vineyard the drift abounds, in a remarkable manner, in masses of chalcedony, some of which are a foot or more in diameter. The pebbles are so numerous that many tons could be gathered on a mile of beach on the north shore of the island. This material is not found on the mainland, nor is it known on the moraine of Cape Cod. It is therefore probable that it was riven from the area now covered by the sea.

CLAY BOWLDERS IN TILL.

The till of Cape Cod, especially where it occurs in the moraines, or has a morainal aspect, occasionally contains large masses of clay which evidently were brought to their resting places in the manner of other erratics. These masses can be found scantily at several places on the cape. They were most clearly shown in an artificial escarpment which for some years existed near the steamboat wharf at Woods Hole, the site of which is now occupied by the Nobska House. In the excavation of a low drumloid hill which existed at the place just mentioned, a dozen or more of these clay bowlders, varying in diameter from a few inches to 6 feet, were noted by me in the course of three or four visits to the locality. Traces of the same bowlders have been seen on the northern slope of the cape and in the district about "Quisset" Harbor. As such bowlders have not been found on Marthas Vineyard in the numerous sections of similar drift materials, it is desirable to seek an explanation of the peculiar limitation of their occurrence. These conditions seem to have been as follows:

The clay of which these bowlders was formed was of a tenacious, uniform quality. Although much oxidized, it was seen to be of the same general character as that found in the brick-clay pits of the region about North Barnstable. That the clay was rather soft when it was moved is indicated by the fact that the surfaces of the masses were crowded with pebbles, in the manner in which lumps of clay, made by the waves on the seashore from the waste of clay cliffs, are coated with a layer of pebbles which have been pressed into the mass. As the glacier evidently slipped over the surface of such clays wherever that surface was of a continuously sloping form, as it now is on the northern versant of the cape, it seems likely that these bowlders were riven from areas where the ground was cut into deep ravines after the manner of the so-called bad-land topography—conditions which would favor the formation of erratics. That such irregularities existed in the cape area is sufficiently shown by the irregular "noses" or projections of clay—the so-called clay "pounds" which have been dug into here and there to obtain materials for bettering the sand roads of the district. So far as I am aware, clay bowlders as large as those at Woods Hole have not been found in other regions. Their rare occurrence is perhaps attributable in part to the fact that a deeply indented topography, formed in soft clays, has rarely been so eroded by an ice sheet. (See Pl. XCIX.)

LENTICULAR HILLS.

The class of drift deposits known as lenticular hills or drumlins is practically wanting in the southeastern portion of Massachusetts. There are no instances in which elongated arches of till are sufficiently well developed to merit a place in this group. Here and there, however, are morainal hills which show distinct traces of the action which gives rise to these regular forms. The ridges north of Woods Hole, between that village and Quamquisset Harbor, closely approach in shape what would be termed drumlins of the lowest order if they lay in the central part of Massachusetts. So, too, on the north side of the cape, some of the drift hills in the town of Bourne show traces of a like regularity of outline. On Marthas Vineyard several of the morainal ridges in West Tisbury and Chilmark, especially that known as Prospect Hill, are distinctly of a drumloid form.

The arched hills of the cape district are, so far as I have observed, limited to the higher ground, and they approach more closely a symmetrical form as the altitude above sea level increases. This is not the case in the more northern parts of the coast of Massachusetts, for about Boston Harbor and in Ipswich very perfect specimens of the type are formed rising from the sea level. In any discussion as to the origin of these curious topographical forms this peculiarity of their distribution must be considered.

It is noteworthy that in this district the drift hills are more shapely on the side against which the ice moved than on that which was turned away from the stream, and also that the ridges of the pre-Glacial topography cut in the sands, gravels, and clays of the Cretaceous, Miocene, and Pleistocene formations have been in many cases rounded into drumloid forms. This is particularly the case on the western side of Marthas Vineyard, though instances of the same nature exist on the central and western parts of Cape Cod. Some of the hills near the Chatham Harbor margin of the Truro beds have a distinctly drumloid outline. (See Pl. XCIX.) These facts clearly point to the conclusion that whatever may have been the cause which led to the local deposition of the deep sections of till composing characteristic drumlins, the final shaping of these forms was due to the action of the ice as it passed over them.

WASHED DRIFT.

In this field, as elsewhere in New England, the washed drift may be divided into three tolerably distinguishable groups: eskers (nearly absent here), pitted plains or kames (rare), and sand plains or morainal aprons. It is to be noted that the materials composing these deposits differ less from those of the ordinary till than is usual in the more northern parts of Massachusetts. Here the till itself is always very sandy, its pebbles are much rounded, and the clay element, as compared with the more northern localities, is relatively small in quantity. This feature is probably due to the diminished cutting power of the glacier on its outer margin and to the extent to which its detritus was worked over by the water which flowed beneath the ice on its way to the front of the sheet. The result of these actions was to diminish the total amount of the till and to make the remaining portion much sandier here than elsewhere. As a consequence of this, it is often difficult to distinguish between the drift which has been deposited in water and that which has been left upon the surface by the melting of the ice in which it was contained.

One of the eminent peculiarities of this district is the general absence of eskers. So far I have not been able to find any characteristic examples of these structures on Cape Cod. In the region from Bass River to Orleans there are certain ridges extending in a north-south direction which may possibly belong to this group of deposits, but I suspect that they are the remains of the ancient topography cut in sands of the Truro series. I am the more inclined to this view for the reason that the one ridge on Marthas Vineyard which I identified in my report on that island as an esker has since been proved by a section to be an old pre-Glacial feature, slightly modified by a coating of washed drift or very sandy till.

The probable absence in this field of eskers of the molds of the caverns in which flowed the subglacial streams goes to support the hypothesis that the ice in this section did not generally rest upon the surface, but came in contact with it only on the higher parts of the ground. Thus floating, there would be no chance for the development of the ice-roofed channels, the shapes of which became elsewhere molded in the débris with which they were in time filled. As these eskers descend to the level of the sea in the district about Boston, and are found in the region north of a line stretching from Boston to Narragansett Bay, it may, perhaps, be inferred that the conditions which are indicated in the Cape Cod district were of a rather local nature.

Pitted plains of the type so common in the districts where eskers exist are not often found on Cape Cod or in the islands to the south. The only good examples are on the frontal apron south of the moraine, where ice remnants, icebergs, or ground ice left by the retreating glacier appear to have been partly buried in rapidly accumulating sands, leaving where they melted depressions to indicate the positions they occupied. A trace of the same action is found in the central part of the great plains of Marthas Vineyard, where the occurrence of a small lake with steep sides can be accounted for only on the supposition that its site marks the place where a stranded iceberg was buried in the accumulation of sands which constitute the mass of the morainal apron.

An ordinary type of kame deposits, consisting of a number of hillocks of arched form huddled together quite without definite arrangement, a type very common in the town of Plymouth, appears to be lacking in the cape and islands. This peculiar local topography of the washed drift can most readily be explained by supposing that when the ice came to the point where it ceased to rest in the bed rock and began to float, its under surface would for a time retain the form impressed upon it by the contours of the surface over which it had flowed. There would thus come to be a space between the base of the rotting ice and the sea bottom into which the débris coming from the land would naturally be crowded. If the ice had much movement the resulting shapes of the drift would of course be destroyed, but at a late stage in the retreat of the glacier its stagnation might be so far complete as to leave the molded sands and gravels as we find them. The occurrence of this remarkable kame topography on the mainland and its absence on the neighboring peninsula and islands is what we should expect on the hypothesis that the ice was in part afloat in this portion of the field it occupied.

The characteristic form of washed drift occurring on Cape Cod and the neighboring islands is the deposit of sand and gravel laid down in front of the moraines. These deposits are more extensive in this district than in any other known to me except, perhaps, on Long Island, New York. It is to be noted that these great morainal aprons differ in certain ways from the sand plains of the mainland. On that field the plains are in most cases at the end of distinct eskers, and clearly mark the places where a subglacial stream passed into the open air or open water. They are rarely, if ever, distinctly related to the axis of defined morainal ridges, though we often find bowldery tracts at about the point where the esker passes into the plain. In these morainal aprons of the cape district, on the contrary, there are no eskers leading to them, but the broad field of sand extends up to or near the wall of coarse débris. Next this wall there is commonly a shallow, wide depression, from which the apron rises to a point somewhere about a mile away, whence it declines to the sea. Such is the form of the great plains of Marthas Vineyard and Nantucket. In Cape Cod the depression or ditch is less distinct; it will, however, be remarked by an observer who has noted the feature elsewhere.

While the ordinary sand plains have their "feeding" eskers—molds of the channels through which the débris came—those that front the great moraines of the cape lack these features. Here and there are breaches or low places in the morainal walls through which currents of water appear to have flowed, as is shown by the signs of erosion in the channels in front of these breaches. The plain exhibits broad, irregular channels which lead down to the sea. These scour ways do not appear to have been at any time occupied by open-air streams, but rather to have been excavated on a water-covered surface. This feature, like the ditch in front of the moraine, is less distinct in Cape Cod than on the neighboring islands, yet it is disclosed to close inspection and partly indicated on the topographical map. In reports on the geology of Marthas Vineyard[1] and on the geology of Nantucket[2] I have given in some detail an account of the characteristics of the plains that lie in front of the moraines on those islands. The like deposit on Cape Cod differs from those noted in the papers referred to in that it is ruder in form, that it has numerous considerable lakes on its surface, and that the scour ways are generally occupied by brooks.

The peculiarities of the morainal apron on Cape Cod, taken along with the evidence of beds of clay apparently belonging to the Barnstable series, lead to the conclusion that in place of the very deep deposit of sand which exists beneath the plain on the above-named islands we have a relatively thin layer of detritus imposed upon a preexisting topography which is cut in rather impervious beds. The numerous swamps and lakes, as before remarked, so high above the sea that their waters could not be retained by sand barriers, are probably to be in part accounted for by the supposition that they lie in valleys which originally drained northward, as appears to have been the case with nearly or quite all of the pre-Glacial streams of the cape. These streams were dammed by the moraine. In perhaps larger measure, however, these basins are to be regarded as the molds of ice remnants about which the washed sands were gathered. That such was the case is shown by the fact that the sides of the depressions are usually very steep, the detritus having slopes which it could not have assumed at the time of its deposition unless there had been some barrier, such as the walls of ice would have supplied, to keep it from being conveyed into the cavity.

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[1] Seventh Ann. Rept., U. S. Geol. Survey, 1885-86, p. 316.

[2] Bull. U. S. Geol. Survey No. 53, 1889, p. 19.

The contours of the great plains of Cape Cod, like those on the islands, clearly indicate that the material was deposited under water. In aerial overwash plains, formed as detrital cones, we find necessarily a continuous down-sloping surface. In these plains in front of the glacier of southeastern Massachusetts the surface has the gently rolling character characteristic of sands that have been arranged on the bottom of a sea which was the seat of tolerably strong currents. The slope of the Cape Cod morainal apron is essentially the same as that of the similar structures in this district, the rate of the decline to the seaward being from 12 to 15 feet to the mile.

The surface of the plain of Cape Cod is prevailingly composed of rather fine, siliceous sand. This material forms a bed having a rather remarkably even thickness of from a foot to 18 inches. This usually passes downward by a rather sharp transition into a pebbly layer in which the pebbles are from the smallest sizes up to that of a cricket ball, though rarely so large. At greater depths the admixture of sand and pebbles is rather uniform, the mass having obscure stratification. Now and then a bowlder is found. These bowlders are almost always rounded and rarely exceed 2 feet in diameter; they are often found in groups associated with gravel, and they occasionally occur on the surface. Such stratification as is exhibited is not distinctly cross bedded. In these, as in most other features, except the presence of numerous lakes, the cape plain in no way differs from the like structures in the other parts of the district.

In considering the origin of these morainal aprons of southeastern New England, the fact should be noted that deposits of like nature do not, so far as I am aware, exist in front of the moraines in the interior of the country. There are there, it is true, traces of overwash plains, but they are always much less continuous; they have, in a word, more of the nature of detrital cones. Those I have seen in Ohio, Michigan, and Wisconsin also lack the depression next the moraine, the pits occupied by lakes such as occur on Cape Cod, and the scattered bowlders in the mass and on the surface of the deposit. The difference between the structure in the two districts probably arises from the fact that those in southeastern Massachusetts were formed under water, while those in the west were deposited mainly in the air. If we suppose that the sea extended up to the ice front, and that the finer materials were, at the time of melting, given into the control of tidal currents, we can well conceive that the part of the débris which could be thus transported would receive a wide distribution over the neighboring bottom; the floating ice would convey many bowlders from the front of the moraine, dropping them haphazard as they melted; the tidal currents would carve channels on the bottom as they cut them on any sands over which they may flow. In a word, the assemblage of conditions exhibited in the morainal aprons is more consistent with the supposition that they were formed on the sea floor than in any other manner.

It will be noted that a number of the peculiar features of these moraines together tend to show that this district was rather deeply submerged at the time of their formation. I have, as yet, been able to find no evidence going to show whether the submergence was so deep as to cover the tops of the morainal walls. It may be noted, however, that on Marthas Vineyard the portion of the moraine which faces on Tisbury River has no apron on its front, but rather a steep overwash plain or long detrital cone which terminates in a valley that may have carried the wash from the glacier down to the neighboring great apron. It thus seems probable that this portion of the morainal front lay above the level at which the sea was placed at the time it was formed.

OUTER LIMITS OF THE CAPE COD ICE SHEETS.

In view of the fact that the ice sheet on this portion of the Atlantic coast was evidently thin, the question arises as to its probable extension beyond the limits to which it can be traced by the remains it has left upon the land. On Cape Cod we find in the Truro-Wellfleet district very slight evidence—if it be, indeed, evidence at all—that the ice lay upon the surface. I am quite prepared to believe that the drift in this area is due to the action of floating ice dropping the waste it carried upon the bottom. We may from the evidence fairly conclude that we are here near the eastward margin of the effective ice sheet.

On the south the extension of the glacier appears to have been to a relatively farther point than in the east. On Nantucket there is a small area of low but fairly characteristic moraine with a well-developed frontal apron. On the island of No Mans Land, south of Gay Head, we have an extensive deposit of a till-like nature, which may, however, be due to floating ice. On the southernmost of the Elizabeth Islands the glacial drift, though scanty in amount, is still sufficient to attest the presence of the ice in that part of the field. It thus appears that the glacier probably extended its action over all the district of Cape Cod, though on the extreme south and east the effects which it exercised may have been due to portions of the ice which had been broken from the united mass and which were floating in the open sea. It is hardly to be supposed that a sheet so thin as the glacier was in this part of its course could have held together for any considerable distance from the shallows, capes, and islands where we last trace it.

In closing this portion of the report attention may be called to the value of the information concerning the frontal condition of the glacier which southeastern Massachusetts affords. In no other section of the country are the data for inquiry so ample—and, it must be confessed, so difficult to interpret.

POST-GLACIAL DEPOSITS.

This group of deposits includes the spits, hooks, and beaches, the dunes, the marine marshes, the fresh-water swamps, the soil, and, finally, the sea shoals.

One of the first-named group of constructions we have in the hook which constitutes the whole of the area of the town of Provincetown, one of the finest existing examples of such forms. There is certainly none other of its kind in this country which so well deserves attention. The history of this feature appears to have been in general as follows:

When, after the disturbances of level which attended the last Glacial epoch, the land of Cape Cod came to its present apparently stable attitude, the elevated country of Truro extended somewhat farther to the north and east than it does at present. As this last portion of the cape in the east was worn down by waves and currents in the manner in which the work is now going on, the débris was, in part at least, carried to the end of the land, there beginning the growth to the northward of the spit. As noted by Prof. W. M. Davis, the sea beach at the north end of the Truro highland marks the point where the encroachment of the sea was arrested by the beginning of the accumulation of sands which has extended to the village of Provincetown. (See Pl. CII.)

It seems likely that there was shoal water where this spit was formed; before it began to form, indeed, the erosion of the northern face of Truro, which has just been noted, may have been part of a considerable wearing that had gone on before the spit had begun to form. There is a bit of evidence on this point drawn from the results of the "driven" wells sunk in the sand at Provincetown which, though not certain, has some value on this point. These wells, which were sunk to a depth of a few feet below the level of the sea, in place of yielding the very pure water which elsewhere has been obtained from such spits, have afforded a quality which, on account of the large amount of iron it contains, is, hardly fit for use. Water of the same nature is characteristic of the old sands of pre-Glacial age wherever they have been tapped in this part of Massachusetts, the defect being due to the complete oxidation of the considerable amounts of iron which they contain, and perhaps to other chemical changes, such as do not occur in the clear siliceous sand of which the spits and beaches of this region are made. It therefore seems probable that the water of the Provincetown wells is drawn, not from the beach sands, but from the lower-lying pre-Glacial deposits.

The process of growth of the Provincetown hook appears to have been mainly by successive beaches, each formed in front of the next preceding, and each projecting northward somewhat beyond its predecessor. The supply of sand seems to have come, in part at least, from the wearing of the coast line of the Truro-Wellfleet district, and in part from the sea bottom to the eastward. There has evidently been a balance of actions which of late has served to urge the sand to the northward toward the present end of the cape. It is evident that for a time no distinct hook existed in the end of this spit; its form was somewhat like that of Monomoy, but, probably for the reason that the water deepened beyond the shallow on which it at first grew, the end near its present stage of growth turned westward to form the hook with which it now terminates.

At first the Provincetown spit was evidently narrower than it is at present, but with the carriage of sands northward along the shore the water on the side of the open sea was shallowed by the formation of a broad shelf which enabled a succession of beaches to form, each somewhat farther out than its predecessor, and in this manner the spit has been considerably widened. This process of growth appears not to be continuous. From time to time, with the varying direction and energy of the waves and of the currents which they induce, the beach works in, again to be built out with the resumption of the carriage of waste from the shore southward.

Along with the carriage of sand by the sea there has gone a considerable movement of materials by the wind. This has taken place mainly in a westerly direction from the outside beaches. When the tide is out and the air dry, even a moderate wind will move the finer parts of the material almost as easily as though it were snow, and in great storms quartz pebbles up to the size of peas may be observed to fly along at the height of some feet above the earth. As the wind loses a part of its speed in passing over the surface of the ground, the particles of sand and gravel which it bears soon fall into the eddies of the current, there forming the beginnings of dunes. As soon as these dunes form they begin to march before the wind; the bits slip up the exposed side and pass over the crest into the sheltered sea, where they remain at rest until the whole mass has been shifted forward in the same manner. In this way, by the process of constantly moving the windward layer to the leeward side, the dune slowly marches inland.

Various influences tend temporarily to arrest the march of these Provincetown dunes, as they do all such masses of wind-blown sand. As the bits journey they decay, so that they naturally cement together. Moreover, certain species of plants, such as the beach grasses, have developed the capacity to grow in the arid soil of these ridges. This they do so effectively that their roots and leaves make a mat which deprives the wind of access to the heaps.

In the present state of the Provincetown spit hook the structure appears, as a whole, to be in a tolerably balanced state, a condition into which such structures are apt to come at a certain stage of their growth. The cape does not appear to be extending northward, unless it be very slowly, the tidal currents from the bay interfering with this growth. The hooked extremity, which is made up of detritus that washed around the end of the cape, does not appear to have gained in extent in a material way during this century. The only change which menaces the established order of this unstable new land is the present inward movement of the beach on the eastern side, near Moon Pond. There we have a well recognized danger that the sea may break through, with the result that the valuable harbor of Provincetown would be endangered. It certainly would become shallower, and it might be so far changed as to lose its present great importance as a port of refuge.

The erosion of the sea on the eastern face of the cape from the northern end of Truro to the central part of Eastham has provided not only the sand which has gone to construct the Provincetown area, but also that which, moving to the southward, has built the large and beautiful line of barrier sand beaches that extends from opposite Chatham Center to the end of Monomoy Island. Although this isle is at present separated from the mainland of the cape by a shallow water way, it is, in its structure, a spit of the same general character as that at Provincetown, only less far developed. Already at its southern end it has begun to form the hook, which is the appropriate finish of such spits.

The amounts of débris which have gone both ways from the erosion district of the eastern face of Cape Cod appear to be nearly equal. The reason why the Provincetown spit is so much longer than that of Monomoy is, that the greater part of the sand which moved southward has been used in constructing the extensive barrier beaches that lie on the sea side of Orleans and Chatham; for these long and broad walls of sand probably contain rather more material than is held in the much more conspicuous spit hook at Provincetown. At present the Monomoy spit appears to be growing more rapidly than its northern equivalent, so that in time these two geographical growths may become even more alike than they are at present.

On the northern shore of Cape Cod, although there are no parts of the shore which are undergoing erosion, there is an interesting system of barrier beaches, which has been constructed since the land assumed its present level in relation to the sea. The material for these beaches has evidently been derived from the shallow bottom of the adjacent bay, it being dragged in to the shore by the action of the waves. It will be observed that while on the eastern and southern sides of the cape these beaches are always drawn near the shore, so that the lagoon they shut in is quite narrow, those on the western and northern shores depart widely from the coast, so that they inclose broad fields of water, such as Wellfleet Bay now presents or such as were found at Barnstable before the harbor was narrowed by the extensive growth of marine marshes. The reason for this more remote position of the barrier beaches in relation to the shores is, that the water on the north side of the cape appears to have been, in the beginning of the present conditions, as it is at present, shallower and with a more gently declining bottom than it had on the south. In fact, the old river basin, which is now Cape Cod Bay, had evidently a much more gradual slope than had the neighboring basins on the south. Thus the ancient form of the basin has served to qualify the shapes of the existing shores.

On the southern side of the cape the evidence of coastal erosion is somewhat the same as it is on the eastern part of the area. In certain places along this shore there are evidences of considerable but variable localized coastal erosion, the waste from which is distributed along the shore and accumulated in slight barrier beaches and hooks. Of these the most interesting is that known as Point Gammon, at the mouth of Lewis Bay. At certain places, as, for instance, at Chatham lights, observations show that for a number of years the recession of the shore went on in a singularly rapid manner, at the rate, it is said, of 10 feet per annum. It is evident, however, that this was a local adjustment of the shore, caused, it is now asserted, by the development of the beach which extends to Point Gammon, and the consequent change in the distribution of the wave action. The amount of erosion on this southern shore has probably been but a fraction of that which has gone from the eastern face of the cape, where, in Truro and Wellfleet, an extensive salient, probably amounting in area to not less than 30 square miles, has been cut away to afford the débris which has been distributed on the beaches, spits, and hooks on the north and south. That the erosion on the eastern face of the cape diminishes in a westerly direction is shown by the unembarrassed outlets of the streams which enter the sound along this shore. If there had been any considerable amount of erosion here, the sands therefrom would have been gathered in adherent and barrier beaches and spits, such as exist along this coast wherever the sea has been supplied with materials from which to make these constructions.

On that portion of the western face of Cape Cod which is bordered by Buzzards Bay we find but little evidence of marine erosion. There are a few very small spits, but no barrier beaches; in fact, there are few portions of the coast south of Boston which are exposed to waves of moderate severity where the amount of work done by the sea is so small as it is here.

This glance at the shore conditions of Cape Cod shows us that only a small part of its periphery indicates any considerable amount of wasting since the land came to its present altitude. The maximum recession can not well amount to more than 3 to 4 miles. This occurred on the eastern side of the Truro-Wellfleet coast. The next most considerable loss is on the section near Hyannis. The best evidence as to the limited amount of the loss of area is afforded by the fact that the extent of the cliff shores of the area is limited; even the frail materials of the morainal aprons have not been much cut away, as is shown by the fact that their slopes are, with rare exception, prolonged down to the level of the tide. Had they been much eroded they would face the shore in steep cliffs.

Owing to a considerable local erosion which has taken place on parts of the shore of Cape Cod, there has come to be a general opinion that the peninsula is in process of rapid destruction. This view appears to be held by many well-informed residents of the peninsula. So far is this view from being true that the converse may be taken as nearer the facts. It is altogether likely that the total area of this cape country, including all the marshes, barriers, beaches, spits, and hooks that are attached thereto, is no greater than it was at the time when, by a final step of subsidence, it established its present relations of land and sea. The aggregate of this erosion is evidently much less than that which has taken place on the islands to the south.

The submarine constructions which have been made by the tidal currents in the waters about the cape are probably, in mass, much greater than are those which appear above the plane of low water. An inspection of the Coast Survey maps discloses in the soundings a curious tangle of shoals, mostly ridge like in form. As before remarked, some of these submarine elevations are probably the divides of the smaller streams which intersected the floors of the valleys at the time they were above the sea. This is clearly the case with Stone Horse Shoal, and it is most likely so with the middle ground of Vineyard Sound. Others, especially the group about the eastern entrance to Nantucket Sound and that at the north end of Muskeget Channel, are evidently due to the action of the strong and contending tidal currents which sweep through these areas of sea. It may be noted here that the absence of any signs of marine current action on the surface of the land of Cape Cod or the neighboring islands and mainland above the level of the sand plains is tolerably good evidence to show either that the Glacial submergence did not extend above that level or that, if more deeply submerged, the ice remained on the surface until the land was reelevated to about its present height.

MARSH AND SWAMP DEPOSITS.

The marine marshes of this district are of considerable extent within the limits of the cape; their area is about 11,000 acres, the greater portion lying on the north side of the isthmus, in the Barnstable and Wellfleet reentrants. On the south and west coasts they are distributed in numerous small areas along the banks of the smaller drowned valleys and in the lagoons lying between the barrier sand reefs and the shore. As compared with the similar marshes north of Boston Harbor, these of Cape Cod exhibit a much less energy of growth. Basins which there would have been occupied by completely developed deposits are here but imperfectly covered by them. The reason for this deficiency is not to be found in any change of species, for these are the same in both districts, but probably in the fact that the amount of mud swept in by the tide is here very small as compared with what it is elsewhere; the result is that the plants are ill fed and do not attain anything like the vigor of growth which they exhibit when the water at each flooding brings much nutritious material to the plant roots. Moreover, in these sandy bays the eelgrass, which is the most effective agent in preparing the shallow water to be occupied by the marsh-making growth, does not do so well on the bottoms of drifting sand as it does on those of firmer and more supporting nature, such as are found to the north.

The fresh-water swamps of Cape Cod were originally very numerous. Though by far the greater number of them have been drained for use as cranberry plantations or converted into reservoirs to flood the vines in the proper season, some areas still remain in their natural state. In its original condition this district had a larger share of swamp grounds than any other equal area in this part of New England, and the inundated fields were more evenly distributed than elsewhere.

The reason for the great development of swamps on Cape Cod is to be found in the fact that there is a clay underlay beneath the glacial sands on the greater part of the area. Thus, the plain of the morainal apron, which in the equivalent deposits of Marthas Vineyard and Nantucket, because it is of pure sand to a great depth, is almost destitute of swamp deposits (that of the first-named island being quite without swamps), is on Cape Cod beset with lakes and with swamps which have grown in lake basins; moreover, the ridge of the old divide on which the moraine rests is wide and rather flat, which favors the development of many areas of imperfect drainage. These conditions have served to give to this region its long-continued predominance in the industry of cranberry planting. There is probably no other place where the very peculiar conditions required for this singular form of agriculture have been so well assembled.

The fresh-water swamps of this region are much better developed than are the marine marshes. The climate and soil are so dry that there is no trace of the climbing action of the bog sponge which is so common in Maine and is still notable about Boston. This general dryness somewhat arrests the growth of the peat deposits, but it favors that of many species of bushes and some trees, such as the swamp maple and the tupelo. The result is that a large part of the peaty matter of the bogs in this district is due to the leaves and stems of phænogamous plants. On this account the bog soils are evidently more fertile than are those formed by the decay of mosses alone. It is in part to this cause that we must attribute the excellence of the cranberry plantations.

It is a noteworthy fact that a very large proportion of the lakes in the cape district have escaped the action of the swamp-making agents. Many of these basins not exceeding half a mile in diameter show no trace of peaty growth about their borders. This feature is probably due in part to the very sandy character of the shores, which makes it difficult for the mosses to become implanted there—a difficulty which is the greater for the reason that the range in the level of the water is very great. In part the hindrance arises from the considerable depth of many of these ponds and the steepness of their beaches, which makes it hard for the water lilies and rushes to take root, so that the protection which their stems afford the shore from the assault of the waves is lacking. The result is that the frail beginnings of a moss plantation are likely to be broken up long before the growth has attained the strength which would enable it to resist the action of the waves.

SOILS.

The soil of the cape differs little from that of the neighboring districts of the mainland and the islands On the north shore, from the base of the peninsula to Orleans, the general presence of the Barnstable clays or the clayey till made therefrom causes the fields to retain moisture in a way they do not in the more southern and eastern sections. On this account, rather than for any special nutritive value in the underlying material, the soil here is considerably better suited to farming than elsewhere. The vegetable matter on which the fertility of the earth so largely depends does not pass out by decay as speedily as it does in the excessively porous débris which generally underlies the surface in these fields.

Owing to the exceedingly sandy nature of the till, except, as before remarked, where it rests upon the clays of the shore, there is little difference between the soils formed on it and those formed on the sand plains lying south of the moraine; in each condition the portion of the earth which is mingled with decayed organic matter, i. e., the true soil, is rarely more than 6 inches in thickness. As the mineral matter in the drift beds of this region is exceedingly well adapted to afford the mineral elements required by vegetation, the failure of a soil to form is rather curious. The reason for the condition seems to be that the exceedingly porous nature of the earth affects plants injuriously; in the first place by causing their roots to become very dry shortly after a rain, and in the second place by permitting the speedy and complete deçomposition of the decaying organic matter, so that the earth is without the necessary amount of humus. The validity of this hypothesis is shown by the fact that wherever we find a place in which the water table is retained sufficiently near the surface to permit the tilled zone to be moistened by capillary attraction from below, there we find excellent ground for tillage; moreover, wherever the plan of plowing in green crops is followed, the results show that the soil needs only suitable treatment to give excellent returns. A considerable personal experience in tilling such soils as the sandier kinds of Cape Cod enables me to say that where they can be irrigated and where they are provided with nitrogenous matter by the inexpensive plan of plowing in crops of peas, clover, or other leguminous plants, they can be made to yield profitable crops.

It is particularly desirable to have the treatment of these soils of southeastern Massachusetts made the subject of a special and well-directed inquiry. In this district we have an aggregate area which may be safely reckoned at not less than 150,000 acres whereon all efforts at tillage have ceased. The region was once fairly well wooded, but the forests have long since been cut away and their regrowth is prevented by the numerous fires which sweep over them and which still further reduce the amount of vegetable matter in the soil. These fields, when unwooded, are sold, in the rare transfers which are effected, at from 50 cents to about $3 an acre; in their present neglected condition they are really not worth any price. In view of their nearness to rail and water transportation they should invite the attention of persons who are willing to take the pains necessary to learn the most economical methods of bringing them into tillage. Sixty years ago the swamps of this district were even more unpromising fields for agriculture than these sand plains and hills, yet at the present time, in their condition as cranberry bogs, they are worth on the average more than $100 an acre over and above the expense of bringing them under cultivation.

Of the total area of Cape Cod, only about one-eighth is so occupied by morainal matter as to be untillable; about another eighth is contained in the sand spits and beaches; so that three-fourths of the whole area is, so far as the geological conditions go, fit to be made into soil, and will doubtless in time be brought under cultivation. The morainal fields afford excellent ground for the culture of forests; several species of trees do well on this bowldery earth, among which may be mentioned the white pine and the Scotch larch, both of which grow rapidly and are free from diseases. In the occasional swamps, so placed that they can not be used for cranberry culture, the swamp cedar, which affords with a rapid growth valuable timber, may be advantageously grown.

Perhaps the only land quite unfit for profitable use is that of the washed and blown sand of the beaches and spits. In the earlier conditions of our agriculture, lands such as those of Cape Cod were not worth attention. At the present time, with the increasing use of fertilizers and irrigation, these fields are likely soon to be made productive.

The facility with which water can be stored in the elevated lakes of Cape Cod invites the use of irrigation on much of its area. From a rough eye estimate (there are no maps good enough to warrant a closer study) I judge that not far from 10,000 acres of the peninsula could be effectively watered.

HARBORS AND WATER WAYS.

In the conditions of navigation down to within sixty years of the present time the harbors of the cape were well suited to shipping. Owing, however, to the fact that these havens, with the exception of that at Provincetown, owe their basins either to flooded valleys, such as Oyster Bay, or to irregularities in the morainal fields, such as Woods Hole, they are all rather shallow and usually are shut off from the sea by bars and shoals. They are, therefore, fit only for the use of the smaller craft. Several of the ports which once sent forth many commercial ships, as, for instance, Chatham and Barnstable, do so no longer. The only port of value on the peninsula is that of Provincetown, which owes its existence to the formation of the curious beach hook which incloses its basin. The havens fit for use of pleasure boats are numerous; they are, indeed, numbered by the score. No part of the coast south of Maine so abounds in them as does the southern face of the cape. In general, these basins are susceptible of much improvement by the use of jetties, which may confine the considerable tidal water which passes through their excessively wide entrances.

More important in a general sense than the harbors of Cape Cod are the water ways which nearly traverse its width. These may be made passages by which vessels can avoid the dangerous voyage that now has to be made by all craft passing this part of the coast. A sailing vessel bound north or south of the cape has to reckon on an average of about two days' loss of time, as well as a considerable expense in the way of insurance, in making the voyage, at least during the winter half of the year. Except Cape Hatteras, there is no more dangerous portion of the Atlantic coast. The shipping which annually passes through Vineyard Sound on this voyage is said to be greater than that which traverses any like width of water in the world. From an early day there have been projects for cutting through the cape, making use of some one of the several channels—rivers so called—which nearly intersect the peninsula. Of these there are four which, with relatively slight expenditure as compared with other modern ship canals, could be opened to shipping. They are Monument River, Bass River, Town Cove in Orleans, and Pamet River in Truro.

The two last-named ways, though from an engineering point of view most practicable, are situated so far out on the cape that the worst dangers of the voyage northward would be passed before their entrances were reached; they are, therefore, not worth consideration.

The Monument River passage is, from the point of view of engineering, at least as far as opening the way is concerned, a very easy work to construct. It has, however, the peculiar disadvantage that it opens into Buzzards Bay, so that vessels must determine on passing that way from the time they start on their course around the cape. As in good weather the course can be run by a sailing vessel in twelve hours from the anchorage ground near Nobska light, in Vineyard Sound, what mariners need is a way to pass from the waters of that sound directly into Cape Cod Bay. The only passage which will afford this is that by the way of Bass River. This channel is, on the average, deeper and wider than Monument River, and it lies in a position where, at reasonable cost, vessels going northward could be provided with a safe harbor of refuge, whence, if the weather favored, they could turn the cape or could take the shorter artificial way. It is probable that the costs of these ways would not differ in any important measure. The distance from the western ports to Boston via Bass River would be longer by about 50 miles than by way of Monument River; to and from points north of Boston the additional distance would not be worth reckoning.

A considerable disadvantage of the Monument River way is that the upper part of Buzzards Bay, owing to its land-locked and currentless state, often becomes thickly packed with ice, even in winters of ordinary severity. On the other hand, the waters of Vineyard Sound, because they are the seat of strong through-running currents, are rarely thus embarrassed. It may be remarked that there is another improvement in the water ways of the cape which deserves consideration only less than a water way across the peninsula; this is, the passage through the morainal line to Woods Hole. At this point a natural breach of the moraine—one of the many which exist in the moraines of this district—affords a crooked and dangerous passage which has been much in use by vessels since the settlement of the country. A measure of benefit has been done to this way by dredging, but it remains an inadequate passage between two of the largest bays on our shore. If Monument River is to be taken as the site of the canal—and by a nearly common consent it appears to have been thus adopted—it will be more than ever necessary to provide a fit ship channel at Woods Hole, so that vessels may still have some choice as to the open route around the cape after they have entered Buzzards Bay.

Whatever is done in the way of canalizing the cape, it is clearly important that an adequate harbor of refuge should be provided on the south shore, where vessels in times of severe storm may find a safe anchorage. At present there is no such shelter fit for the use of the larger vessels which ply along the Atlantic coast between New Bedford and Provincetown. The anchorages in Vineyard Sound, with the exception of the small havens at Woods Hole and Edgartown and the breakwater at Hyannis, are all open and exposed to grave danger from the northeastern gales. The most available of these shelters—that at Vineyard Haven—is often very much crowded, so that if the outermost ships should drag their anchors a great catastrophe would be likely to occur, in which scores of vessels might be lost. A considerable number of the shipwrecks which occur where craft are on their way around Cape Cod are due to the fact that there is no perfectly safe place in the waters of Vineyard or Nantucket sounds where they can await conditions of weather which make it fit to essay the passage.

ROAD-BUILDING MATERIALS.

The condition of the highways in Cape Cod is and always has been bad. The sandy nature of the underlay and the prevailing lack of vegetable matter in the soil make this condition inevitable unless some method of hardening the wheel way is adopted. Of these methods there are four which are more or less available at various points: The roads may be covered with oyster shells or the shells of the pecten, known locally as the scallop; they may be covered from time to time with a coating of clay; they may be graveled; and they may be macadamized.

The use of shells is in many ways to be commended where the traffic is light; but when exposed to much travel the covering is swiftly destroyed. Moreover, any general use of this material is impracticable on account of the limited sources of supply. The use of clay as a means of hardening the sands has been essayed in this district, but with poor results. The application on roads of ordinary use has to be made about once in two years, and it is so costly that in the end it is more expensive than it would be to construct a well-hardened way. Of gravel fit for road building, none is known to me except in the extreme western portion of the cape, and this is not of good quality. Thus the only satisfactory resource in this field is found in the use of broken stone, as in the well-known macadamized roads.

As there are no bed rocks attainable in the cape district which can supply material for macadamizing, it is necessary either to import the broken stone from the farther parts of Plymouth or Bristol counties or to make use of the erratics which may be had from the moraine or from the old walls composed of the smaller bowlders which have been gathered from the fields of till. As far out on the peninsula as the central part of Orleans, and within this section southward to the border of the moraine, the amount of this erratic material is great. It is, indeed, sufficient for the needs of road building in this county for all the foreseeable future. The supply of "field stone," or those which may be had from the surface of the ground, of sizes to be used in the crusher without breaking with the sledge, is limited. It is not likely to serve for more than the needs of original construction of the roads which will have to be built within the next score of years. After that the resort will have to be the pits opened in the moraine, where usually more than half the mass excavated will be large bowlders needing to be blasted in order to be made serviceable.

The petrographical character of the morainal erratics is good. They are mostly of a granite nature, with some admixture of trappean rocks. These dike materials sensibly increase in amount as we go eastward along the moraine. In this direction we find a considerable amount of volcanic débris, mostly fragments of what seem to be indurated ash beds and breccias. As before remarked, the rock masses of this morainal accumulation are not much affected by decay. The experiments made by the Massachusetts Highway Commission in the use of the field stone on the cape—of which about 12 miles of way has already been built, a portion of it having been in use for two years or more—shows that this material is excellently well adapted to building roads. It is so slightly decayed that the amount of small fragments produced is not much greater than is needed in "surfacing" the roads. When this element is excessive an adjustment can be made by sorting the stone before crushing, the product of the softer kind being used in the lower layer of the construction.

Roads made of the bowlders found on the cape can not be expected to have the endurance to traffic that is exhibited by those which have the covering layer composed of the harder traps, such as are found in the region about Boston or in the Connecticut Valley, yet for the uses they have to serve in this district they will prove very good.

The portions of the cape which are ill supplied with road building stones are those in the southern parts, between the western part of Mashpee and the eastern part of Chatham and the towns of Eastham, Wellfleet, Truro, and Provincetown. In the first of these districts beneath the morainal apron there are, as are shown by various ditches, extensive deposits of pebbles and bowlderets which may afford local sources of supply of stone to be used in the crusher. These should be assayed in order to avoid the great cost of hauling material from the source of supply in the moraine, which is distant and accessible only by very sandy roads. These pebbly deposits seem to lie beneath the beds of the channels which extend from the moraine to the shore. They are usually covered by a thin layer of gravelly sand. The supply for the portion of the cape beyond Orleans will have to be brought by railway from the morainal district, and fortunately the railway extending to Provincetown brings all parts of this section within an average distance of about 1 mile from transportation.

ORIGINAL EASTWARD EXTENSION OF CAPE COD.

The presence of an extensive system of drowned valleys on the Cape Cod district, including therein the islands on the south, leads to the question as to the extent to which these partly submerged lands were originally continued to the eastward. This question can not be fully answered, but some light may be thrown upon it by the facts and considerations which are noted below.

It is at a glance evident that the eastern side of the river valley into which drained the streams on the north side of the cape has been in part cut away. There is nothing to mark its former place except it be in part the shoal in which the Provincetown hook has been formed. This shoal is indistinctly continued northward, as is shown by the soundings, and the general form of the bottom of Cape Cod Bay supports the hypothesis that the valley was continued down to the depth of 100 feet or more below the present level of the sea.

On the floor of Massachusetts Bay and farther to the seaward in Georges Shoal, Cashes Ledge, and other less important elevations we have the elements of what appears to be an ancient land topography. It is possible to explain these features by the supposition that they are due to the warping of the earth or by the hypothesis that they were morainal in their nature, but neither of these views finds any definite support. Warpings of the type required to account for the facts would have to be of a type unknown in this part of the continent, at least in recent geologic periods. Moraines are contraindicated by the slight erosive power the ice evidently possessed and the thin character of the morainal accumulations on the neighboring coast.

It might seem probable that the mountain-building actions which led to the extensive dislocations of the Tertiary strata in this district were competent to bring about the formation of such ridges as we find on the sea floor in this vicinity, but the vast erosion and deposition which has taken place since these disturbances occurred would naturally have led to the destruction of any such reliefs had they been formed. Moreover, there are no indications that the stressing of these beds led to the building of sharp ridges, such as we find in these ledges and shoals. On the contrary, it is eminently probable that the region thus affected lacked at the end of the process any distinct topography except such as was given it by subaerial erosion.

It seems certain that the topography of the sea bottom in and to the east of Massachusetts Bay can not be very ancient. It evidently lies within the limits of the continental shelf—i. e., within the realm of excessive sedimentation, next the shore. Reliefs of such a sharp character would inevitably have been covered by detritus if they had long been in existence. Therefore, the probability seems to be that they are a part of the topography which, in a semisubmerged state, is preserved in the Cape Cod system of drowned valleys.

The cause of the formation of the partly or completely submerged valleys of this part of the shore may perhaps be found in the extensive dislocation which the strata have undergone in this region. If we suppose, as we well may, that the newer deposits of this part of the coast were over a large area much mountain built, the result would have been to lift what was originally a set of level and low-lying beds to a considerable height. A topography developed on such strata would be sharp, and the headwaters of the streams would be at a higher level above the sea than would be the case in the neighboring undisturbed districts. The fact that like disturbances in the region lying to the west and south have been attended by a similar preservation of the ancient topography, as in Long Island and Block Island, makes this view as to the cause of the maintenance of the Cape Cod peninsula the more probable.

In considering the conditions which have led to the formation and preservation of the Tertiary topography in the Cape Cod district, it is well to note the fact that the whole of this portion of the Atlantic coast appears to be at the present time much below the average elevation which it has recently had. This is shown by facts which indicate that the sea has not of late laid at a higher lever than about 100 feet above its present station, while the evidence from the submerged topography leads us to the conclusion that the depression below the level of most extreme elevations has amounted to at least 300 feet, and probably is much in excess of that amount. It should also be said that this submergence is not due to local causes. It is clearly a part of the very general action which has included a large portion of the shores of all the continents. The action is manifested on the eastern coast line of North America, from the mouth of the Rio Grande to the circumpolar section of the continent. It is also to be noted on the Pacific coast within the same parallels.

ABSENCE OF SHOALS IN CAPE COD BAY AND IN BUZZARDS BAY.

The absence of shoals in Cape Cod Bay and in Buzzards Bay apparently indicates a difference in the history of these basins as compared with that of the depressions of Nantucket and Vineyard sounds. The explanation may possibly be found in the fact that the sounds, in part at least, represent a region of adjacent headwaters of several streams the cols of which were in the last great subsidence lowered beneath the sea, permitting the tidal currents freely to pass through them. These streams having a great erosive action on soft rocks, such as underlie this district, are sufficient to account for the effacement of the islands which evidently lay not long ago in these waters. It may also be remarked that the Buzzards Bay River appears to have had a steeper drainage than the other neighboring old streams on the east, which may have accounted for the more complete erosion of the divides between its branches. It seems, however, more likely that the presence of these shoals in the Nantucket and Vineyard system of sounds is partly to be attributed to the action of tidal currents in this field.

SEAWARD CONTINUATION OF DROWNED VALLEYS.

The soundings given on the coast charts, where the water exceeds about 100 feet in depth, are not in sufficient detail to make it worth while to devote much labor to tracing the probable direction of the ancient drainage channels with a view to ascertaining how near they went to the margin of the continental shelf. We may, however, note certain of the more patent facts.

North of Cape Cod we find a deep channel between Race Point and Stellwagen Bank. The water at the western end of this channel, where it appears to connect with the Cape Cod Bay Valley, has a depth of about 35 fathoms; thence it shoals seaward to about 22 fathoms; still farther to the east it deepens rapidly to about 50 fathoms. The shallowest water in this channel is in the continuation of Cape Cod. Stellwagen Bank has a minimum of 12 fathoms of water upon it, and not much more for its length of about 20 miles; then at the deep channel leading toward Boston Harbor the bottom suddenly declines to the depth of 60 fathoms. The evident suggestion is that Stellwagen Bank is a northward continuation of the Cape Cod divide and that Race Point channel marks the position of a col on the ridge, which was some 70 feet lower than the general surface of the water shed; and also that the Cape Cod Bay River joined what we may call the Boston River near the northern end of the above-named bank.

North of the valley of Boston River another less distinct, unnamed shoal continues the line of Stellwagen Bank in such manner as to suggest that a stream corresponding in a way to that of Cape Cod Bay headed about Cape Ann and flowed southward, joining the Boston River near where that passing from the Cape Cod divides entered it, the united streams flowing on through the Stellwagen ridge to the sea. The general likeness of the outlines of these antithetic valleys, if we may use that name to designate basins of very like character whose streams flow against each other, suggests that they are carved in like materials, or, in other words, that the Cretaceous and Tertiary strata of the Cape Cod district are continued as far north at least as Cape Ann, though they do not appear above the surface. This proposition is made the more probable by the discovery by Mr. Warren Upham of fossils of possible Eocene or Cretaceous age in the drift materials near Highland light. As such remains have not been found elsewhere in the drift of the cape, they have probably been brought from beneath the level of the sea.

Evidences derived from soundings and dredgings in the Bay of Maine indicate, as is well known, the existence of Tertiary and perhaps Cretaceous rocks, at least about the Grand Banks and Georges

Bank.[1] These and other observations indicate that the shoals to the east and north of Cape Cod are probably the remains of ancient divides, and the soundings warrant, in a measure, the interpretation of ancient river valleys, but this task will not here be further essayed.

ORIGIN OF THE CAPE DISTRICT PLATEAU.

An inspection of the contour maps will show that the pre-Glacial beds of the cape district, including the islands on the south, have their upper surfaces everywhere at about the same altitude, with a prevailing slope from the western part of Marthas Vineyard, where they rise to about 300 feet above the sea, toward the east and north, declining at Boston Harbor to the sea level, near the end of Cape Cod to a little above that level, and at Nantucket to a height of about 50 feet. The question arises as to the origin of this approximately plane surface. It may be due to either of two actions—to base-leveling or to the leveling action of the sea—or possibly to a complex of these actions. It clearly is inadmissible to suppose that the plateaulike surface is due to the survival of the original stratification surface, for, as has often been noted, the area has been greatly disturbed. Against the supposition that the approximation to horizontality just before the uplift which set at work the streams that cut the valleys of the old rivers of this district was due to base leveling, we may note that this would require us to suppose a very long period in which these much-dislocated rocks had been slowly brought to a level by atmospheric agents. As we see at present on Marthas Vineyard these rocks yield but little to such action. The streams of to-day carry away scarcely any mud; their effect is limited to a slight leaching action. To introduce such a base-leveling period of sufficient duration would call for greater lengthening of the first Pliocene time than it is reasonable to make.

The leveling of this district by the action of the sea might have been accomplished in a relatively short time. The present rate of retreat of the southern shore of Marthas Vineyard is, as before noted, about 3 feet per year; at this rate the sea would occupy 2,000 years in wearing a mile into the land. The width of this table-land, including the submerged portion, being assumed at 50 miles, the leveling process would have required about 100,000 years. Great as this time is, it is probably much less than would have been required to effect the same result by the base-leveling process alone. Here, as elsewhere along coast lines, it is likely that these two actions cooperated, the streams carrying away what they were enabled to and the waves removing the portion of the material which was not thus taken to the sea. It is not likely, however, that the time occupied in the work could have been much less than that above suggested. Here, again, we encounter the perplexing difficulty that the history of the beds of the successive epochs in this area requires us to suppose a lapse of time since the close of the Tertiary period much greater than is commonly assumed to have occurred.

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[1] A. E. Verrill, Occurrence of fossiliferous Tertiary rocks on the Grand Bank and Georges Bank: Am. Jour. Sci., third series, Vol. XVI, p. 323.

POSITION AND CHARACTER OF DIVIDES.

The position of the several divides which mark the limits of the ancient partly drowned valleys of the Cape Cod district is such as would be expected in case the topography of the region had been developed when the surface of the country was at least 200 feet higher than it is at present. The most continuous of these crests is that of the cape itself, extending from the town of Plymouth eastward to Chatham and thence northward to the sand spit which terminates the cape. This divide may have been continued somewhat farther to the east, as will be noted hereafter. The arrangement of the valleys of the headwater streams in this section suggests their former union in two or more valleys, which declined to the north and south. North of the elbow of the cape to the Provincetown sand spit the incutting of the sea appears to have destroyed the original crest of the divide, leaving only the slope of the ridge which drained into the Cape Cod Bay river.

The divide which separates the water of the last-named stream from the upper tributaries of the Buzzards Bay river is still traceable in the long ridge which stretches in an interrupted manner from Monument River to the neighborhood of Plymouth Harbor, terminating in Manomet Hill. It is, indeed, impossible to account for the very peculiar shape of the ground in this district without supposing that it is due to the interlacing of the headwaters of adjacent but oppositely flowing streams. This western divide of the Buzzards Bay valley is continued southward in the united ridge on which the Falmouth moraine lies as far south as Woods Hole. From the harbor of Woods Hole the same divide is shown in a less united form by the line of the Elizabeth Islands to and including the island of Cuttyhunk.

On the south of Vineyard Sound we have in Marthas Vineyard the remains of the other crest of the valley of which the Elizabeth Islands form the other divide. This crest constitutes the northern range of hills of Marthas Vineyard, extending as far east as Vineyard Haven. The central and southern parts of the highlands of the island are on the headwaters of streams which seem originally to have flowed into the Muskeget River valley.

The island of Nantucket appears to be the remnant of several obscure divides, but the greater part of what is left above water is on the slope of the drainage toward the Muskeget and the Monomoy rivers. As will readily be seen, the directions of the ancient rivers in this portion of the district are by no means clear. This obscurity is mainly due to the extensive erosion by tidal currents which has taken place in this part of the field.

It is to be noted that the decline in the altitude of the principal divide of this district, that which extends from Plymouth Harbor to the extremity of the Elizabeth Islands—a distance of about 45 miles—is relatively steep, being from a height of about 300 feet to that of about 100 feet above the sea, or an average of about 5 feet per mile. In view of the considerable width of the valleys in this region, this decline must be regarded as greater than is consistent with the supposition that the region is anywhere near to being completely base-leveled. There is no definite evidence as to the rate of fall of these drowned valleys, but in valleys of such width, cut in materials of so yielding a nature, it is difficult to believe that it could have exceeded 5 feet to the mile. In considering this question it should be noted that the decline of the crest line is not necessarily a true measure of the fall of the valley. In general, however, this decline is, at least in the upper part of the river's course, much less rapid than the fall of the stream. Taking the remnants of the valleys as we find them in Marthas Vineyard, we note that they support the proposition that the bottoms of the old valleys had a slope less than is indicated by their present altitudes. The valleys of the Tisbury and Tiastquan rivers below the points where they are occupied by permanent streams have a fall of about 15 feet in a mile, yet these are the upper and presumably steepest portions of the river systems to which they belong. Although there are no very certain conclusions to be drawn from this inquiry into the slopes of the old rivers of the Cape Cod district, the fact suggests that there may have been some warping movements since the topography was formed.

It is to be observed that the three best defined of the old valleys of this area, those of Cape Cod Bay, Buzzards Bay, and Vineyard Sound, show a certain measure of narrowing toward their lower parts. This feature is most evident in the case of Buzzards Bay, but it is noticeable also in the other basins. This apparently indicates stream erosion working toward the formation of circus-shaped valleys, features which are not uncommonly found in much eroded areas.

In connection with the old valleys of this area the island of No-man's-land offers matter for interesting inquiry. This bit of land, by its position and its relation to the form of the sea bottom, suggests that it is the remnant of the southern divide of a valley the stream of which drained into Vineyard Sound river near Gay Head. The shoal about this island, though it is evidently subjected to much erosion by the strong current and waves, indicates that the isle, which is rapidly wearing away, was originally of much greater extent than at present. The retreat of its shores, which appears to be going on at the rate of about 3 feet per annum, will bring about its destruction in less than a thousand years. Its place will then be for a time occupied by a shoal which, under the cutting action of the waves and tidal currents, will be planed down to a considerable depth, coming finally to the state of the shoals in Nantucket Sound.

TRESPASSING OF RIVERS.

The position of the several divides between the ancient basins of the Cape Cod district indicates that the streams had advanced far in the development of their topography before the last great subsidence. Here and there we find evidence that the crests had been brought to rather sharp edges, having in most cases lost all trace of the original table-land character which seems to have been in some way impressed on them before the last invasion of the valleys took place. The Cape Cod crest was evidently sharp; so, too, was that of the Elizabeth Isles. That of Marthas Vineyard was of a more complicated nature, retaining much of the original table-land form.

The process of stream capture, of which there are good instances on Marthas Vineyard, which evidently took place before the last great downsinking that brought about the formation of the bays and sounds, shows that the adjustment of the topography about the heads of the streams on that island had not been anywhere near completely effected. Similar though less evident indications of such action on the mainland may be found in the valleys of Monument, Bass, and Pamet rivers, where streams had evidently in good part or altogether cut back through the divides, more or less invading the drainage of the antithetic stream. In two of the last-mentioned instances, Monument and Bass rivers, the transgression seems to have been made by streams flowing southward toward the valleys of the Nantucket Sound area. In that of Pamet River the slope seems to have been to the westward into Cape Cod Bay. The passages between the Elizabeth Isles were apparently much as we now find them before the close of the time preceding the last deep submergence. If this be the case, the head streams of either the Buzzards Bay or the Vineyard Sound river may have crossed the divides, and as these passages have been much changed by glacial action and by tidal currents it is not easy to determine in which direction the trespassing waters flowed.

As the valleys now occupied by the bays were evidently rather deep, probably at least 500 feet at their deepest part, below the higher parts of the divides, the incomplete nature of the topography on and near the crests is no good reason for supposing that their bottoms were much indented. It is a very common feature of river valleys to have their lower parts level and their upper parts deeply indented. We thus are not compelled to suppose that a great deal of filling has been necessary in order to bring about the general approximation to horizontality exhibited in the bottoms of the bays.

AMOUNT OF SEDIMENTATION SINCE THE PRESENT LEVEL WAS ESTABLISHED.

As noted under the last heading, the fact that the bottoms of the Cape Cod system of bays and sounds are approximately level can not be taken as evidence of any great amount of sedimentation since the sea attained to about its present position at the end of the last important down-sinking. A close study of the form of these bottoms, based on the soundings of the United States Coast Survey charts, shows a multitude of slight irregularities which can not well be attributed to the differential deposition of sediments due to tidal currents, but can best be explained by supposing that the layer of imposed detritus is not yet thick enough to completely mask the preexisting ridges and valleys of these submerged areas.

If there had been a great amount of deposition on the sea floor in the Cape Cod bays we should expect to find all the original irregularities of surface due to their erosion quite effaced, in the manner in which it appears to have been destroyed on the great southern plain or on a lesser scale on the morainal plain of Marthas Vineyard; but while there are traces of such depositional shelves near the shore, as on the southern coast of the last-named isle and along the south and east shores of Cape Cod, these shelves are narrow and flat. In form they evidently are quite unlike the bottoms of the water areas at a distance of 2 or 3 miles from the coast line. The evidence from soundings goes to show that the migrations of sand in these areas are locally considerable, but they appear to occur only in the paths of relatively strong tidal currents, such as sweep through the sounds and in the bays; it is to the effect that, notwithstanding all the coastal erosion which is going on, the contribution of sands to the bottoms of the bays at the distance of a mile or more from the shores is very slight in amount. These facts lead me to doubt whether as much as an average of 50 feet in depth of detritus has been accumulated on the floors of the bays since they last came below the level of the sea.

On the south side of Marthas Vineyard and of Nantucket and on the east side of Cape Cod the considerable invasion of the land by the sea has doubtless done much to contribute material for sedimentation, but in Cape Cod Bay and Buzzards Bay the erosion of the shores has not been sufficient to supply more than a few feet of detritus over the floors of the basins. The waste of organic life deposited in these basins is relatively small in amount, being much less than in those parts of the shores and shallows to the northward, where mollusks and seaweeds are more abundant.

Owing to the situation of the Cape Cod salient it is not in a position to receive detrital materials from a distance in the manner in which they are accumulated along the shore south of New York. North of the cape the deep trough passing outward from Boston Harbor intercepts the current and wave driven waste coming from the northern shore. On the southwest there is no set of currents driving such material toward the waters of the sounds and bays. Some contribution may have been had from the wreckage of islands now reduced to shoals, but it probably has not been in large amount.

DEPTH BENEATH SEA LEVEL AND NATURE OF THE CRYSTALLINE ROCKS IN THE CAPE COD DISTRICT.

At no point in the district of Cape Cod are the ancient crystalline rocks exposed to view, nor does the drift covering on any part of the land indicate by its character that these deposits are on the land areas, at least near the surface. In passing from the mainland toward the cape we find the nearest localities of the crystalline rocks at Plymouth Harbor and on the west shore of Buzzards Bay. Throughout the southeastern section of Massachusetts these rocks exhibit a gentle and tolerably uniform slope toward the base of the cape at the rate of about 20 feet to the mile. This would place the old granite series at the level of 100 or 200 feet below the sea level on the eastern shore of Buzzards Bay and at a depth below that plane of about 1,000 feet at Chatham Harbor. Inasmuch, however, as all this region has been greatly disturbed, and as the disturbances most probably included extensive movements of the ancient rocks as well as of the Mesozoic and Cenozoic strata which rest upon them, no great value can be given to these estimates.

On Marthas Vineyard and scantily on the shores of the southwestern portion of Cape Cod, particularly along the southeastern side of Vineyard Sound, as before remarked in the account of the glacial drift, a great quantity of chalcedonic quartz pebbles are found. So abundant are these coarse agates that hundreds of tons of the material could at times be gathered along the shore. It is evident that these fragments have been glacially transported, and, as is indicated by the character of the layer of erratics as well as by the glacial scratches, the movement of the ice was from the northwest, if indeed it was not from a point nearer the west. Nowhere on the mainland are rocks of this nature known either in situ or in the drift. Along with these chalcedonic erratics go great quantities of pebbles of white-vein quartz of an aspect quite different from any known on the shores to the northward. A close comparison of the pebbly materials on the islands of the Cape Cod district with the rocks on the mainland will undoubtedly show other cases of this kind. On the body of Cape Cod, in increasing proportion as we go from Monument River eastward, we find groups of vein and volcanic materials differing in nature from those on the neighboring islands. In this last-mentioned district the pebbles of volcanic rocks are very abundant, especially in and beyond Orleans.

The evidence afforded by the erratic materials of this district shows that just to the seaward of the shore line there is both to the north and the south of Cape Cod a belt of rocks which have been the seat of great volcanic and solfataric action, and that these deposits have been much metamorphosed. In this connection it may be noted that a belt of disturbance of the nature indicated on the sea bottom about Cape Cod begins in the region about the Bay of Fundy and extends parallel to and partly within the shore along the coast of Maine. I have noted the occurrence of such conditions in the published accounts of work done for the Survey in the districts about Passamaquoddy, Cobscook, and Orange bays, and in the district of Mount Desert and on Cape Ann. In the two first-named fields the presence of distinctly volcanic deposits is well proved. At Cape Ann evidence of true volcanic action is lacking, but the extraordinary amount of dike injections, which evidently increases as the shore is approached, shows the effect of the same system of disturbances. It thus appears probable that the coast line of this continent, from the head of the Bay of Fundy at least as far to the southward as the mouth of Buzzards Bay, lies upon the inner margin of a tract which has been greatly subjected to volcanic and solfataric action. It is not improbable that the indentation of the first-named bay may be due to the subsidences connected with these disturbances and that the position of the coast line on this part of the shoreland is to be accounted for either by the downward movement or by the relative ease with which the coastal fringe of rather incoherent deposits were eroded by the sea. Interesting as these questions are, they can not be followed further here except to suggest that the volcanic areas of the Boston Basin, of the Connecticut Valley area, and of the region in and near the lower part of the Hudson Valley, where there is reason to suspect that the volcanic rocks are newer than the Newark beds, are within the limits of this marginal fringe of such deposits.

FOSSILS DREDGED FROM SEA FLOOR NEAR CAPE COD.

From time to time there have been reports that fossils of a character which would indicate that they came from beds such as are found on Marthas Vineyard or at Marshfield existed on the sea floor to the north and east of the cape. These specimens have been brought up on anchors or by the dredge. It seems likely that in all these instances the materials have been derived from the drift deposits on the floor of the sea, though it may be possible that, as about Georges Bank, the considerable energy of the tidal currents may scour away the soft parts of the bottom, leaving the harder fragments as a coating on the sea floor.

The evidence above referred to, though fragmentary, and at best not very trustworthy, is enough to show that to a considerable depth, say to 200 feet or more, the bottom is, in part at least, occupied by the fossiliferous deposits which were here and there exposed in the cape district just before the Glacial period. This serves to show that the erosion which took away so large a share of the later pre-Glacial accumulations—those designated as the Truro and Weyquosque series or the Barnstable clays—affected a large extent of the sea bottom for a considerable distance out to sea. Without attaching too much importance to this obscure evidence, it may well be taken as of some value in showing that the region was for a long time elevated to the height of 200 feet or more above its present level, or, what comes effectively to the same thing, that the sea was at about that depth below its present plane. Thus the considerations going to show a recent submergence, which are derived from the topography of the coast and the drowned valleys, has some support from the evidence which these chance samples of the bottom afford.

It has been suggested that these fossils brought up by dredging may be from the drift deposits which are presumed to exist for some distance to the east beyond the shore. Against this hypothesis may be set the fact that fossils of the Cretaceous and Tertiary beds have rarely been found preserved in any glacial deposits, even where those beds lay immediately upon the strata richest in organic remains. The probability that they would thus occur in quantities sufficient to account for the numerous chance finds is so small that it may be disregarded.

TIME RATIOS INDICATED BY POST-TERTIARY PRE-GLACIAL EROSION.

It is not possible, in the present state of our knowledge, to undertake any final essay in determining the time occupied in the erosive work done in this region since the close of the Pliocene epoch. It is, however, possible to give some general and relative indication of these durations.

The facts show that after the deposition of the Pliocene deposits of Marthas Vineyard a vast erosion occurred, which shaped the strong topography that is exhibited in the western part of that island. In the present condition of that area, though the valleys are deep and much of the surface is but slightly drift covered, the rate of stream erosion is almost nil. Even in times of heavy rain the brooks show hardly a trace of color due to other than the stain of decayed vegetation. In the period before the deposition of the drift the rate of wear was probably more rapid than it is at present, but it is impossible to estimate the value of this difference. We are therefore left to mere impressions as to the time required for the development of this topography. These inferences, however, are of some importance.

It is in the first place to be noted that the rocks of this region are, and have been from the time of their formation, very open-textured. They readily absorb the rain water, which cuts no channels on these areas, which are so nearly driftless that the Cretaceous and Tertiary deposits are essentially at the surface. This must have made this field, with any rainfall, which was not very much greater than that of to-day, one of slow erosion, for the reason that the waters entering the ground would have been discharged, as they now are, at the level of the permanent streams and in a very gradual manner. This action may now be seen in fields of great extent, as in the town of Chilmark, or near Gay Head. Nor can we suppose that the water penetrating to the depths exercises any considerable solvent action. The strata which it traverses contain very little soluble matter, and the springs—save that they sometimes exhibit the results of decomposing pyrites in the sulphureted hydrogen they give off and contain a considerable amount of alumina sulphate—are essentially pure. The facts above noted lead to the conclusion that the erosion of the Vineyard area has from the beginning been slow.

On the basis of a slow erosion we have to account for the formation of river valleys a mile in width and having a depth of from 150 to 200 feet, as well as for the renewal of an unknown section which has been worn away from the crests of the hills. Assuming that the average ablation of the area has been at the rate of 1 foot in one thousand years, a rate which must be accounted rapid—it is equaled, so far as ascertained, in no part of the world which bears a covering of natural vegetation—in that it would at this rate of cutting require somewhere near 200,000 years to carve out these valleys; but, as is easily seen, the valleys are only a part of the result of the erosion which the streams have applied to them. The elevated country between these troughs has also gone down, so that it does not seem unreasonable to assume that the total erosion of this valley-making period has required 300,000 years.

Beyond the clear evidence of a long erosion interval afforded by the valleys of Marthas Vineyard we perceive that there is an unmeasured and perhaps immeasurable time which intervened between the period when the rocks in which the depressions exist were dislocated and that when valley-making began. It seems tolerably evident that in this period the sea stood some hundred feet higher than it does at present and that the surface was gradually base-leveled until it came nearly to the plane indicated by the highest land of the island. This little-indicated period of erosion, the sole evidence of which is found in the faint yet distinct marks of an ancient plain, antedating the formation of the present drainage system, possibly represents a duration several times as great as that shown by the action of the streams which now are at work.

In a general way following the development of the valleys of Marthas Vineyard and those which were formed in the tilted deposits of Cape Cod, came a period of deposition in which the various beds of Nashaquitsa, Barnstable, and Truro series were laid down. The history of this stage or stages in the development of the cape district is not yet unraveled. These several sections may all be of the same age or they may represent, to a greater or less extent, the history of successive periods. However this may be, there can be no doubt that the time occupied in the deposition of these beds was very great, and that the detritus which was accumulated came in part, if not altogether, from areas north and west of the cape district, as is shown by the fact that the beds in question to a great extent mantle over the ancient topography and rise to near the level of its highest elevations.

Following the accumulations of the Truro-Barnstable groups came the third great period of aerial erosion in this field. During a period of elevation which brought the land to a level at least 200 feet higher than it is at present, the erosive work of the streams cleared away the deposits of stratified sands, clays, and gravels from the valleys which it encumbered, and extended the denudation of those broad and thick sheets of strata until only remnants of the original mass remained. The amount of erosion effected during this period immediately antedating the last ice epoch can not be gauged, for the reason that the greater part of the area in which it was effected is now submerged beneath the sea; but it was clearly much greater than that which was done in the time to which we owe the development of the several valleys of Marthas Vineyard or the like troughs of Cape Cod. To it we owe not only the general clearing out of those troughs, but the excavation of the river basins which are now marked by the bays and sounds of southeastern Massachusetts.

In considering the time required for the formation of the later stratified deposits of the Cape Cod district we have first to note that the accumulation of these beds indicates a long period of erosion, the record of which, as before remarked, is not found in this area for the reason that it was then beneath the sea. As the work done was of sufficient magnitude to form a broad sheet of detritus, extending from some point far inland, probably the central highlands of Massachusetts, to and beyond Truro and Nantucket, having a thickness on the average of not less than 100 feet, and perhaps several times as great, it is evident that the time occupied could not well have been less than that attained for the second erosive period—that which shaped the greater valleys of Marthas Vineyard. The last great erosion period—that which morcellated the stratified deposits which overlapped the old mountain-built beds—appears to have required more time than any of the earlier periods of wearing. The valleys were brought to a great width. Nearly all the deposits of the last formations were removed, leaving only fragments of them on or near the divides. As this work was done mainly on very permeable beds, into which the rain penetrates rapidly without developing small, superficial streams, the work of wearing could not have proceeded with great rapidity.

The facts as above presented lead to the conclusion that since the close of the Tertiary period, or perhaps from some time after the end of the Pliocene epoch and down to the advent of the ice in the last Glacial epoch, there have been four tolerably distinguishable periods of erosion in this field, each requiring a time the duration of which, even in a geological sense, must be accounted as long. Various estimates, made on the basis of the present rates of erosion, lead me to the conclusion that this interval was not less than one million years.

Without attaching any definite value to the reckonings as to the durations of the periods in which the wearing down on this district was effected, it may be claimed that no geologist who has attentively considered the problems of time ratios in erosion is likely, on a careful study of this field, very much to reduce this estimate. Although the assumption of something like a million years for the interval between the end of the Tertiary and the beginning of the last ice epoch is not in accordance with the views as to the time ratios in the later stages of geological history which were entertained down to the beginning of this decade, it is becoming evident that the old view as to the brevity of this interval was hastily taken and will have to be revised. It is in order to bring this point into debate that the previous estimates as to the time occupied by the completed succession of actions which have taken place in post-Tertiary pre-Glacial time are here submitted.

It may be remarked that the prejudice in favor of a brief time since the close of the Tertiary period has rested in part on the fact that the amount of consolidation which has taken place in the deposits of that portion of the earth's history has been in most cases small. It is, indeed, difficult to believe that beds which have been as little changed as the strata of this age usually are have been formed for millions of years. When, however, we note that in Mesozoic rocks, and even in those of the Paleozoic sections, the amount of alteration is often slight, we can well understand that these more recent deposits, which have not undergone deep burial, have survived for ages without essential change.

SUMMARY AND CONCLUSIONS.

The results of the observations noted in the preceding pages of this report justify the following statements relating to the Cape Cod district, and particularly concerning the peninsula of that name.

After the erosion of the Cretaceous and Tertiary beds disclosed on Marthas Vineyard, several series of sedimentary deposits were laid down. The first of these deposits, which may fairly be reckoned as of early Pleistocene age, though deposited in horizontal attitudes on the disturbed older beds, were in turn somewhat stressed, the resulting dislocations being relatively much less considerable than those which affected the Cretaceous and Tertiary deposits. These dislocations are evident not only on Marthas Vineyard but throughout the area of Cape Cod between Woods Hole, Bourne, and Highland Light. They also extend up the coast at least as far as Plymouth Harbor; their western extension is not yet determined.

The post-Tertiary deposits just referred to appear to be divisible into two groups, the lower of which is exhibited on Marthas Vineyard and in Cape Cod as far north as Monument River and eastward to Orleans. This series is characterized by the presence of red clays and sands, which appear to owe their origin to the decomposition of Tertiary strata such as occur at Gay Head. Apparently above these beds, which have been termed the Nashaquitsa series, occurs another series, here known as the Truro. The characteristic of these beds is that they plentifully contain a fine, white, floury, micaceous sand, which is very much decayed. These sands are combined with coarser arenaceous materials and occasionally clay beds, the clay being of the ordinary grayish or yellowish hue. So far as is ascertained, these beds contain no pebbles of compound rocks, the pebbles, indeed, being very rare and, so far as observed, of quartz, and always small. The Truro series has not disclosed any materials apparently rising from decomposition of the Tertiary beds. It is possible, but not probable, that the Nashaquitsa and Truro series should be regarded as one group. The distribution of the beds, however, is against this view.

The group of brick clays known as the Barnstable series appears to have been laid down after the Nashaquitsa and before the Truro beds had been formed and dislocated. The evidence as to this succession, however, is not perfectly clear.

During the deposition and erosion of the series above noted the Cape Cod district has been subjected to a number of movements of elevation and subsidence of which the imperfectly interpretable changes are shown in fig. 87, p. 522. These movements indicate very remarkable instability in the position of this portion of the continent from Jurassic time to the present day, but the alterations of level appear to have been limited, so far as determinable, to a range not exceeding, perhaps, 1,000 feet. It is to be noted that these accidents appear to increase in frequency as we approach the present day. This, however, is most likely due to the fact that the records are more complete and interpretable as they come toward the present time; possibly, also, as my colleague, Mr. J. B. Woodworth, has noted to me, for the reason that the later records are more coastal in their nature than are those afforded by the earlier deposits. It is to be remarked as a very significant feature that the series of deposits from and including the Nashaquitsa to the close of the Barnstable series have afforded no fossils. It is possible, but not probable, that fossils may have been contained in these beds, the remains having disappeared under the very free leaching which has occurred throughout this area, where the rocks are extraordinarily porous.

It is possible, and perhaps probable, that these beds, in part at least, represent deposits in advance of glacial sheets. Nevertheless, as we have to suppose that in part the materials were laid down in salt water, it is not easy to understand the complete absence of organic remains, which, as we know from other fields, even those near by, as on Nantucket and on the coast of Maine, contain abundant fossils. Moreover, it is difficult to believe that during the extended topographic changes which occurred while the three series above mentioned were depositing, and also during the period of dislocation, which is marked in the attitude of the beds, no ice could have remained near enough to the district to affect the character of the sediments. Still further, the absence of erratic rocks in the Nashaquitsa and Truro contraindicates the action of ice.

The condition of the deposits contained in the series of the Cape Cod district, formed after the close of the Tertiary and before the advent of the glacial sheet, indicates the rapid erosion of an area of crystalline rocks which had previously been affected by a deep decay. It is conceivable that this erosion, acting on softened materials, was due to rivers, but the general absence of vegetable matter in the deposits makes it perhaps more likely that the work was accomplished by glacial erosion occurring during the periods of subsidence which are indicated by the sections.

The facts stated in the preceding pages of this report make it clear that the post-Tertiary and pre-Glacial history of southeastern Massachusetts is much more complicated than has hitherto been supposed. The interpretation of the record which has been given must be regarded as in a great measure tentative. A further development of our understanding of the facts will doubtless be attained when the related deposits on Long Island, New York, have been explored. There is reason to hope that in that field may be found the passage from the conditions of southeastern New England to those accepted in the related Columbian beds and other recent deposits in New Jersey and the portions of the coast to the southward.

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